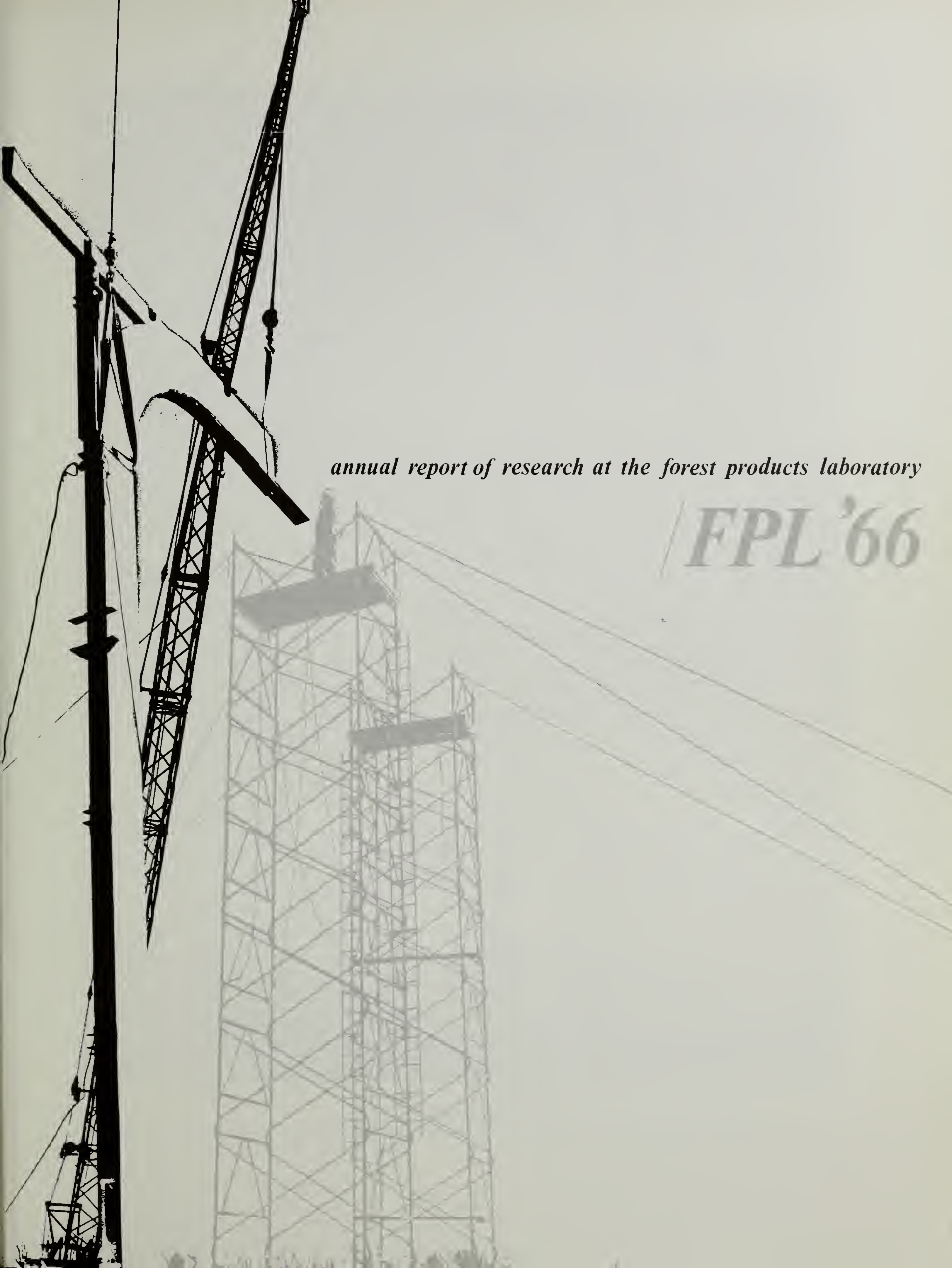
esearch at the forest products laboratory

FPL '66

u. s. department of agriculture - forest service



annual report of research at the forest products laboratory

/FPL '66

EDWARD G. LOCKE
1904 - 1966

FOREWORD

For each of the past 5 years this page has carried the signature, *Edward G. Locke,* Director. On it were summed up those developments in FPL's research which he considered the year's most significant. This year that cannot be. On December 19, 1966, Dr. Locke succumbed to an illness he had endured for many months.

As its sixth Director, Dr. Locke administered FPL for 7 years. They were busy, productive years; productive of research, and productive of administrative acts and decisions that enriched the research harvest and built up FPL's capabilities for greater future productivity. Nor did his contributions end there. In the finest Forest Service tradition, Dr. Locke intuitively grasped the implications of FPL's mission: to do research and disseminate its results, for the greatest good of the greatest number. To fulfill that mission, he worked tirelessly.

He extended and reinforced FPL's relations with other research organizations here and abroad, taking a vigorous personal part in the activities of the International Union of Forestry Research Organizations. He renewed and strengthened FPL's associations with industry, seeking as well as offering counsel and guidance. Cognizant of future research needs, he encouraged the development of new talent in wood science and technology at educational institutions through on-the-job training, fellowships, and grants.

He envisioned and translated into structural reality the first major expansion of the Laboratory's physical plant in 35 years. He was not privileged to see it completed. During his last active months, however, he was able to watch its form emerge beneath his office windows. Fittingly, one room will be dedicated as the Edward G. Locke Memorial Seminar Room.

When FPL's second half-century began, Dr. Locke directed that an annual report of research be published. Since 1961, these reports, including the present one, have inevitably mirrored his contributions along with those of the research staff and associated personnel. As in previous issues, therefore, this page is entitled Foreword. You are invited to read this Annual Report as another such documentary mirror.

Alan D. Freas

ALAN D. FREAS
Acting Director

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President Lyndon B. Johnson presents U.S. Department of Agriculture's cost reduction achievement award to Diana M. Smith, FPL scientist, at ceremonies in Washington, D.C.

THE YEAR IN GENERAL

As this Annual Report went to press, it was announced by Secretary of Agriculture Orville L. Freeman that Dr. Herbert O. Fleischer, Director of the Forest Service Division of Forest Products and Engineering Research in Washington, D.C., had been appointed Director of the Forest Products Laboratory. Dr. Fleischer, a former Chief of the Division of Solid Wood Products Research, was an FPL staff member for 22 years before he assumed the Washington position.

Perhaps as well as anything, the hard hat symbolized the year 1966 at FPL. Prescribed attire in certain areas, the metallic skull shield in its various shapes and colors became virtually haute couture for scientists, clerks, and administrators as well as construction craftsmen.

The new vogue in headgear was inspired, of course, by the all-engulfing surge of construction activity as work proceeded on the erection of a new pilot plant and laboratory building for research in wood fiber products. As the year drew to a close, preparations began for the removal of the grinders, digesters, beaters, paper machine, and other paraphernalia of pilot-scale pulp and paper research crowded into parts of three floors of the main Laboratory building. And in those areas, hard hats became practically de rigueur for all—scientists and secretaries, technicians, clerks, messengers, guides, and visitors.

Nor does the fashion in head dress promise to fade away soon. In the Fiscal 1967 budget, Congress appropriated $180,000 for planning the remodeling of the main building. Long-range Forest Service plans also visualize additional construction, including a

Concepts New and Old Blend in Buildings

Of wood and plastic, sand, cement, and synthetics, workmen built the new FPL pilot plant and laboratory for wood fiber products research.

1. The wood-arch-framed pilot plant juts northward from main building. **(Photograph courtesy of Wisconsin State Journal.)**
2. In January snow and cold, towering arches rose.
3. Covered with weather-tough polyvinyl fluoride, stressed-skin panels of plywood, lumber, and polystyrene insulation are locked into pilot plant walls.
4. Cranes and slings erected 50-foot-high wood arches.
5. Sash of ponderosa pine treated with pentachlorophenol preservative encloses window bays of pilot plant.

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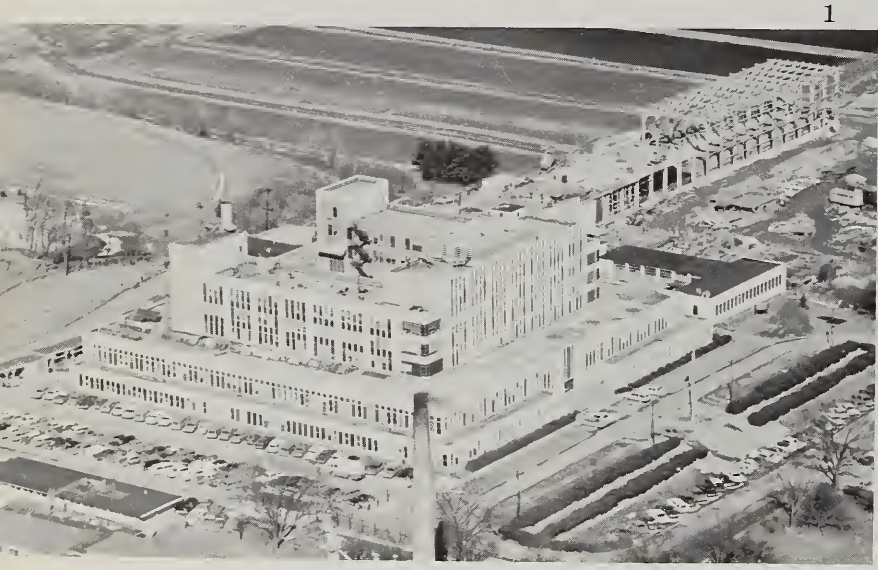

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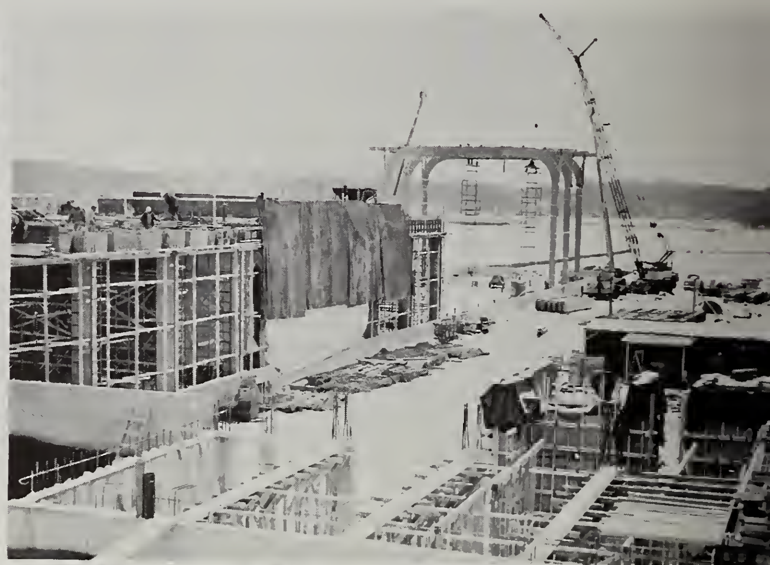

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6. Sixty-foot-long laminated wood girts span columns, arches of pilot plant walls.

7. Arch-enclosed interior of pilot plant is completely unobstructed.

8. Fire-retardant-treated sheathing and redwood siding enclose fanloft atop laboratory building.

9. By late autumn, both buildings are enclosed.

10. Two-piece arches frame two-story south half of pilot plant.

11. Pilot plant is roofed with lumber, wood-fiber insulation, and builtup roofing.

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Wayne C. Lewis, left, FPL engineer, was given the American Society for Testing and Materials Award of Merit by retiring ASTM President Robert F. Legget, Ottawa, Canada. Mr. Legget is director of the Building Research Station of the National Research Council of Canada. M 132 206

George M. Jemison, Forest Service Deputy Chief, Research, presents U.S. Department of Agriculture diamond pin to Miss Helen Kaether, FPL secretary, to mark her 50-year career. M 130 918

wood chemistry building and one for solid wood products research.

With the raising of the first glued laminated wooden arch of the pilot plant in mid-January, construction moved apace. By early summer, workmen were enclosing the all-wood superstructure with some 800 stressed-skin plywood panels, each 4 by 8 feet in size with a tough outer film of polyvinyl fluoride plastic and an interior one of resin-treated kraft paper. Meanwhile, the adjoining office and laboratory building went up floor by floor to its full four-story-plus-fanloft height. As winter fired its first icy blasts, the workmen were comfortably indoors installing piping, conduit, wiring, ductwork, fixtures, and other furnishings.

Meanwhile other research-related events, though sometimes seemingly eclipsed by the tumult of the construction activities, nevertheless added notable pages to FPL history. These included a U.S. Department of Agriculture award for cost reduction achievement by a Laboratory staff member.

President Lyndon B. Johnson made the award at Washington, D. C., to Diana M. Smith for her part in developing a device called a dual linear micrometer for rapid measurement of cells in wood. Cost savings of up to $30,000 a year are possible with the instrument. Blueprints have been made available to other laboratories here and abroad. Miss Smith, project leader in charge of studies of environmental, growth, and silvicultural effects on wood, also received a $500 cash award from the Laboratory.

FPL employees received the National Safety Council's Award of Merit for their 1965 safety record. With only one lost-time injury recorded in 1965, an award-winning injury-accident frequency record of 1.13 per million man-hours worked was achieved.

The Award of Merit of the American Society for Testing and Materials was presented to FPL Engineer Wayne C. Lewis for his contributions to ASTM work since 1947. For 6 years Lewis was chairman of ASTM Committee C-16 on Thermal Insulating Materials, and for 18 years chairman of Subcommittee 15, Committee D-7 on Wood. He also served on Committee C-20 on Acoustics.

An extraordinary award was earned by Miss Helen Kaether, who was given a diamond pin for her 50 years of service as a stenographer and division secretary. Miss Kaether retired at year's end.

An FPL alumnus, 91-year-old Harry D. Tiemann, received the first distinguished service award of the Society of Wood Science and Technology. Mr. Tiemann had retired as FPL's chief physicist and wood drying authority 21 years earlier and was internationally regarded as the "father of wood science" for his many contributions. He originated the concept of the fiber saturation point in wood, basic to all wood drying technology, and contributed greatly to kiln drying and related technological developments. Mr. Tiemann passed away November 18 at his Madi-

son home.

In a major staff change, Dr. Robert L. Youngs was transferred from his FPL position as chief of the Division of Solid Wood Products to the position of Assistant to the Deputy Chief, Research, in Washington, D.C.

The Forestry Research Advisory Committee of the U.S. Department of Agriculture met at FPL October 17-22 for its annual review of Forest Service and related research programs. The committee, consisting of businessmen, educators, and forestry and conservation experts, submits recommendations for guidance and direction of the Department's forestry research to Secretary of Agriculture Orville L. Freeman.

While several auxiliary buildings were torn down to make way for the new pilot plant and laboratory, one such "victim" was given extraordinary attention. A 29-year-old one-story experimental house built originally to demonstrate the then-new concept of stressed-skin construction was carefully moved to the new Building Research Park at the north end of the Laboratory grounds. There it will continue under periodic observation of its durability for many years to come. It became the second "tenant" of the park. The first was a new building featuring pole and slant-leg rigid frame construction. Others, including the first full-scale Nu-Frame house demonstrating a new FPL concept of componentization, will follow.

As national headquarters for Forest Service research on wood, FPL serves the public, industry, and other Government agencies in many ways. Related work in forest products utilization is done at nine Forest Experiment Stations. This report presents summaries of research progress at FPL in the following pages.

Dr. Irving B. Sachs demonstrated the electron microscope as a wood research tool to members of the Forestry Research Advisory Committee of the U.S. Department of Agriculture who met in Madison for their annual review of forestry research. From left, standing, are Ralph H. Bescher, assistant vice president, Forest Products Division of Koppers Co., Pittsburgh, Pa.; Kenneth B. Pomeroy, chief forester, American Forestry Association, Washington, D.C.; Prof. Reynold E. Carlson, in charge of recreation and park administration, University of Indiana, Bloomington; John A. Zivnuska, dean, School of Forestry, University of California, Berkeley; and David J. Ward, committee executive secretary, Washington, D.C.

M 130 703

SOLID WOOD PRODUCTS RESEARCH

It is difficult to assign dollar values to many of the benefits of the Laboratory's solid wood products research. Nevertheless, the problems themselves are often definable in monetary terms that vividly suggest the potentials for benefit. A few examples in the area of work carried on by the Division of Solid Wood Products Research indicate their breadth.

1. Fire costs the United States $1.5 billion a year in direct property losses, another $3.5 billion indirectly in wages, taxes, and the like. The combustibility of wood remains one of its most serious handicaps with respect to code acceptance in many communities. The availability of reliable fire test and performance data on wood, or lack of it, could easily affect the utilization of wood for structural application and interior finish for buildings by 10 percent, plus or minus.

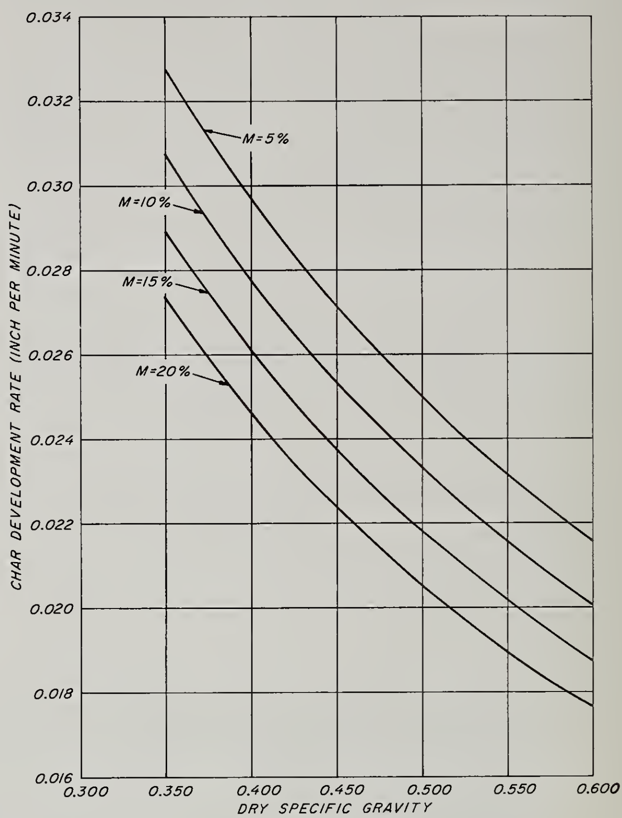
2. Wood drying from the original green condition to levels suitable for various uses costs an estimated $1.625 billion a year. Of that total, loss of quality through warp, splits, and other degrade amounts to at least $500 million. Better knowledge of moisture movement mechanisms through wood and related physical phenomena, coupled with new and improved seasoning processes, could substantially reduce these costs.

3. Wood machining, beginning with the breakdown of the log on saws and continuing through various cutting, surfacing, sanding, boring, and molding operations, costs the consumer heavily in terms of sawdust, slabs, edgings, shavings, and other discarded wood substance. The yield improvement potential of slicing, as compared with gangsaw breakdown of cants into ½-inch lumber, is estimated at 20 percent. Commercial use of slicing is limited, for lack of technology, to production of thin veneer.

4. Inadequacies of existing exterior paints and other finishes for wood have cost the lumber industry 30 percent of the house siding market in recent years. About 1.5 billion square feet of siding and trim are used per million houses built.

5. Decay and marine insects swell maintenance costs of United States Navy wharves, piers, piling, and other wooden shore installations to some $500 million a year. Under some conditions of service, other materials are increasingly used.

This list could be indefinitely extended. Every homeowner is familiar with maintenance problems indoors as well as out. The wooden pleasure boat, despite its advantages, has lost heavily in a booming recreation market. Substitute materials, often imprinted with fine wood grains, are used extensively in furniture, TV and stereo cabinetry, and other products.



Under a standard fire, Douglas-fir is shown as a typical case to char more slowly as moisture content increases for a given density. M 130 376

In one way or another, all of these losses constitute penalties that the wood products industries pay for technological deficiencies. Conversely, these same losses offer a yardstick for gaging research needs in this area.

During 1966, the Laboratory's research produced basic information of major significance to the producers and users of solid wood products.

Fire Endurance of Wood

Among structural materials, wood has the unique ability to insulate itself against heat as it chars during combustion. The importance of this phenomenon has long been generally recognized among builders, underwriters, and code authorities. A landmark study defining this ability much more precisely than ever before was completed during 1966 in cooperation with the National Forest Products Association.

In this study it was shown that the specific gravity and moisture content of wood measurably affect the rate at which fire penetrates the wood. In experiments with three species, Douglas-fir, southern pine, and white oak, specimens at four moisture content

levels from 5 to 20 percent and ranging from 0.35 to 0.60 in specific gravity conclusively demonstrated this relationship. The experiments were conducted under the standard temperature scale of American Society for Testing and Materials Designation E119. In addition, the critical char-formation temperature was shown to be 550° F. for all three species. The standard charring rate of 1/40 inch per minute or $1\frac{1}{2}$ inches per hour was found to apply to Douglas-fir of average specific gravity and 10 percent moisture content.

Both the rising temperature condition of ASTM E119 and constant temperatures were employed in the experiments. Under both temperature conditions, it was shown that woods of higher moisture content and specific gravity char more slowly. A mathematical model equation was developed to express this relationship.

The study also showed that conversion of the wood to charcoal and the combustion of the volatile products resulted in release of 3,100 to 3,500 calories of heat per gram of dry wood, or about 70 percent of the total heat available in the wood.

Industry has put these findings to use in testing structural assemblies for fire rating purposes. By grouping various species primarily according to specific gravity, it is possible to obtain fire ratings for each group by testing only assemblies consisting of the species of lowest specific gravity in each group. The number of fire tests necessary to establish a rating for a group of species is thus greatly reduced.

The study involved specimens exposed to fire on only one face. This work is being broadened to include exposures on one, three, and four faces to study char penetration into sections up to 9 inches thick and 10 feet square.

In laminated structural members, plywood, and other glued constructions, the fire endurance of adhesives is also critical. Experiments designed to yield information on this were also completed for six types of adhesives in Douglas-fir and southern pine laminated beams. Sections 1 inch thick were cut from the side of the beams so as to include all glue lines. The adhesives were rated on the basis of observed char depth at the glue lines, delamination, and wood failure in the uncharred area. Results showed that the most resistant adhesives were phenol-resorcinol and melamine. An adhesive containing 60 percent of melamine and 40 percent of urea resin was somewhat less resistant, followed by a casein and a urea, and in last place a polyvinyl.

The information on the melamine-urea formulation and the casein glue was furnished to the American Insurance Association for consideration in determining the acceptability of the melamine-urea in laminated structural members.

Wood Shingle Treatments

A wood shingle roof that burning brands can't ignite and that won't support flame is a goal of fire research now well under way. Promising new treatments are being rigorously evaluated under controlled laboratory, outdoor exposure, and burning conditions to compare their potential fire resistance and service life. Full evaluation of each treatment will take more than 5 years.

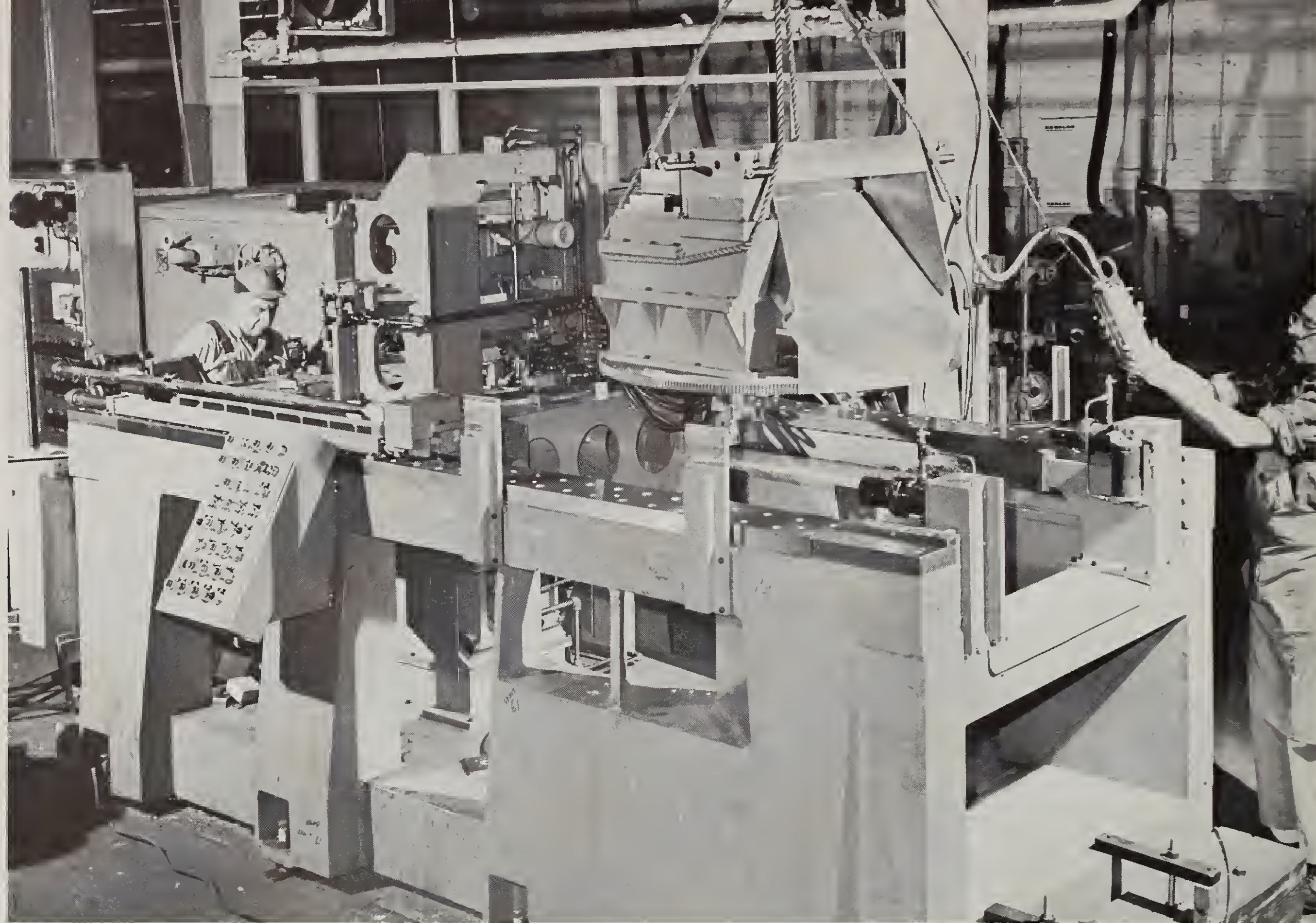
Fire-retardant-treated wood shingles are given Class C burning brand test by Carl Holmes (left) technologist, and Ron Knispel, technician.

One major shortcoming of known fire-retardant treatments is that they don't survive weathering. Rain leaches out the chemicals.

A main object of the research is to find nonleachable chemicals that are economical. Eighteen treatments have been screened. Of these, twelve are getting further evaluation after passing tests in which gas flames of standard temperature seared the surface of treated wood shingles and burning brands were dropped on a roof section.

To compare methods of application, each chemical is applied to shingles by brush, by simple dipping or soaking, by hot-and-cold bath, and by pressure. Pressure treatments put more chemical into the wood but are more expensive, and cost is critical in the competitive shingle business. Each treatment is evaluated by intermittently spraying roof sections covered with treated shingles outdoors with water for 28 days. This reveals whether a chemical can be leached from the wood or breaks down under sunlight.

The shingles that survive are tested for 1,000 hours of alternate water sprays and ultraviolet radiation for 4-hour periods. They then are put once more through both burning-brand and gas-flame tests to find out what accelerated aging has done to the treatment. Treated shingles passing this will be put



The cutter-blade mount of the new FPL experimental wood-cutting machine is lowered in place at a Milwaukee machine-tool plant as construction of the complex device proceeds. Designed for maximum flexibility of adjustments and controls, the machine will be used for research on wood slicing and other methods of cutting. M 132 319-7

through three final exposures outdoors for 1, 3, and 5 years.

One treatment passing the 28-day leaching test and some burning-brand trials is a synthetic resin system originally developed for fire-retardant treatment of washable fabrics at the Southern Utilization Research and Development Division of the Agricultural Research Service, U.S. Department of Agriculture. It is tetrakis hydroxymethyl phosphonium chloride (THPC) in a blend of urea and melamine resins.

Other chemicals under surveillance include zinc borate; organic phosphate resin systems; water-soluble salts in wood coated with a protective sealer; fire-retardant paint coatings; and a two-step treatment with solutions of sodium borate and zinc chloride, which react in the wood to form nonleachable zinc borate. In cooperation with the Tennessee Valley Authority, which has developed ammonium pyrophosphate fertilizers, some of these are being tried.

Fire-Retardant-Treated Particle Board

Most fire-retardant chemicals lower the strength of particle boards by various degrees, depending on the type of resin binder used to bond the particles together. This was demonstrated in experiments with ½-inch flake-type Douglas-fir boards in which fire-retardant chemicals were incorporated.

Least affected were boards with melamine and phenol-formaldehyde resin binders, most of which had acceptable strength properties. Boards made with a urea-formaldehyde binder, on the other hand, were seriously weakened. Among retardant chemicals tried, monoammonium phosphate gave the best results. Diammonium phosphate reacted with the wood. Boron-containing chemicals such as borax and boric acid apparently reacted with the phenol-formaldehyde binder, weakening boards made with it.

Southern Pine Veneer

Southern pine bolts should be heated to 140° to 160° F. before being cut on the rotary lathe to get veneer of best cutting quality. This was clearly brought out in an investigation of the effects of various lathe settings and wood temperatures on veneer roughness and strength. Evaluations were made with 6-inch-long disks of wood cut on an experimental lathe. Variables investigated included knife deflection, deflection of the fixture holding the knife and roller bar, computed load on the roller bar, veneer thickness, veneer roughness, veneer strength in tension perpendicular to the grain, and moisture content of the veneer after cutting. Results also indicate that veneer from heated bolts could be handled with fewer splits.

Experimental Cutting Machine

An experimental cutting machine designed to fac-

ilitate study of cutting speeds, feed methods, angle of wood grain to cutting blade, and forces exerted in cutting and imposed on tool parts was nearing completion at a Milwaukee factory at year's end. The machine was scheduled to be shipped to the Laboratory by early spring for tryouts.

Intended purely as a research tool, the machine is an outgrowth of research on the cutting of thick veneer with a commercial veneer slicer. The capacity of the commercial machine had been reached at thicknesses around one-half inch. It was not capable of cutting wood at various angles to the grain, measuring forces, speeds, and strains, or accepting other types of cutting blades.

The new machine will accept various types of cutters, including saws and sanders. It will eventually include such new cutting concepts as water jets, ultrasonic vibration, and perhaps lasers. The saddle, which holds a flitch of wood up to 10 inches thick and 20 inches long, has a speed capacity varying from 1 inch to 500 feet per minute. Both saddle and cutting knife can be rotated to change the angle at which the wood approaches the cutter. Pressure exerted by the nosebar can be controlled and measured. Forces exerted on the frame and other parts of the machine during cutting can be measured.

The machine will first be used to continue experiments on slicing of thick veneer. During its design and construction, this research has been conducted on a modified metal-milling machine which has demonstrated that wood can be sliced into pieces up to 1 inch thick under controlled experimental conditions. These experiments were conducted on yellow-poplar, Douglas-fir and chestnut oak. Clear-wood specimens were cut at various calibrated roller-bar settings and at room temperatures and 200° F. The hot wood cut much better than the cold. Under the best conditions, yellow-poplar sliced 1 inch thick was free of fractures, and Douglas-fir and chestnut oak fractured less than half-way through the thickness of the slice. Most of the slices were smooth, thinner than the indexed thickness of cut, and were curled toward the roller bar side of the slice. Loads developed in cutting were as high as 2,000 pounds per inch of wood being cut.

Press Drying

Successful experiments with a new press drying technique for production of attractive wood paneling and flooring stock from low-grade red oak logs, as described in the 1965 Annual Report, were continued on other species. Cypress, elm, ash, hickory, white oak, post oak, blackgum, and sweetgum were also tried.

The oaks showed a large amount of checking and honeycomb, but produced interesting character markings suitable for paneling. Cypress, elm, ash, and hickory yielded attractive paneling. The gums dried satisfactorily, but were not exceptional in appearance as paneling.

Basic studies of the press-drying process are continuing. It appears to be most efficient in the middle part of the drying operation. In its present state of development, it appears to be economically feasible for use in plants where excess press capacity is available.

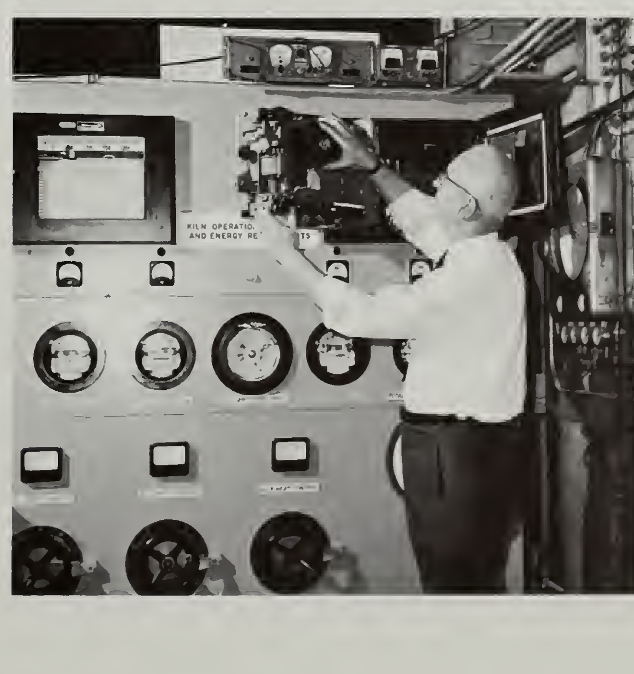
Drying Strains and Sets

A comprehensive study of strains that develop in ponderosa pine during kiln drying was concluded. Air velocities somewhat higher than those ordinarily used in commercial kilns were employed. The study provided data on the complex interactions of the stresses and moisture movement within the wood during drying as a guide to further softwood drying research. Explanations were found for degrade-causing checks in boards containing both sapwood and heartwood or sapwood that develops unusually irregular moisture distributions. A pattern of kiln-humidity reduction that was found to help avoid such checks should have considerable practical application as the lumber industry moves toward higher kiln air velocities. Some of the strain results appear suitable for computer-programmed analysis to determine definite drying stress values based on moisture gradients and the perpendicular-to-grain mechanical values previously determined by Wood Engineering Research.

Automated Dry Kiln

The removal of water from wood during kiln drying obviously lowers the weight of the kiln charge. This fact has been utilized by FPL drying specialists in the design of instrumentation that automatically changes the temperature and relative humidity con-

Weight-recording apparatus of experimental automated dry kiln control equipment is adjusted by Kenneth E. Kimball, FPL research engineer. M 132 532-2



ditions according to schedule as the weight of the charge changes. Experiments have demonstrated the feasibility of the concept in a small dry kiln, the floor of which rests on load cells that activate the instruments.

The instruments are geared to respond to predetermined units of weight change, eliminating the need of making such changes by a kiln operator. Moreover, the changes can be made at any time of day or night that the desired change in weight occurs—not next morning or the Monday after a weekend. Greater kiln efficiency is thus possible by shortening drying time.

One object of the experiments is to develop a package of instruments that can be connected to some existing kiln recorder-controllers. Included in the package would be a pallet-type floor on which the charge could be piled. Load cells in the pallet would signal weight changes in the charge to the instruments as moisture is removed. Such a package would permit automating virtually any type of modern dry kiln equipped with humidity and temperature controls.

Sun-Follower

During the early spring of 1966 a strange-looking contraption whose main visible feature was a pair of gray metal arms holding a large flat panel skyward began a solitary chore that has continued ever since in a field near Madison. Apparently stationary, its arms could be seen to move and shift their burden only over protracted periods. To some it suggested a device poised for takeoff into outer space.

And so it was appropriately named a "sun-follower" by its FPL designers. Permanently anchored to a concrete foundation, however, its function is to keep its panel at all daylight hours directly perpendicular to the sun. To that end a gear mechanism causes its arms to change position constantly, swinging from due east at dawn to the western horizon at sunset. The controls also tilt the panel to coincide with the sun's seasonal change of position.

The goal of all this maneuvering is to assure a maximum of exposure to solar radiation. That goal is being attained. More than twice as much radiation strikes the panel each day as hits specimens mounted on a nearby fence. During the summer, surface temperatures on white panels carried by the sun-follower average 10° F. higher than ambient air temperature and 5° F. hotter than those of specimens mounted on exposure racks at a 45° angle.

The doubled radiation had the expected effect of hastening the deterioration of paint and varnish films on wood specimens mounted on the sun-follower. Experiments continued through the fall and winter to get temperature and radiation data needed to establish the true extent of speedup the device makes possible in the testing of weathering capabilities of various materials. That is the ultimate goal—to get faster weathering of experimental materials and hasten their evaluation for commercial uses.

FPL Engineer Arthur L. Koster, right, adjusts gear mechanism of "sun-follower" he designed while Meteorologist Gene Wengert inspects wood specimens mounted on the panel that is swung constantly by the arms of the device as the sun's position changes. M 132 051

Moisture Content of Wood in Use

Environmental research aimed at fully defining the service conditions for which wood products must be designed is now well under way on a broad national basis. Three forest experiment stations—the Southeastern at Asheville, N.C., the Rocky Mountain at Fort Collins, Colo., and the Pacific Northwest at Portland, Oreg.—are conducting jointly with FPL a broad study of moisture content of laminated wood beams in use under various environments such as those found in swimming pool enclosures, cold storage lockers, churches, food processing areas, and outdoors.

Equipment especially designed for this work includes a tiny moisture probe, ¾ inch long by 0.07 inch wide and thick, that is inserted in wood beams and columns. The probe can be wired to a moisture meter for periodic reading of moisture content. Readings will be taken quarterly over the next several years.

The first series of readings, taken in September 1966, indicated that the moisture content of wood products varies greatly in a given location, depending upon conditions of the immediate environment. Laminated beams for a swimming pool enclosure, for example, had moisture levels greater than 30 percent, while similar beams in a church had only 8 to 9 percent. Statistical analysis of such data gathered over a period of years is expected to yield valuable design information for laminators and other manufacturers of wood products.

Vapor Barriers Affect Heat Loss

Another environmental study, conducted in a small

structure housing instrumentation at the Madison exposure site, demonstrated that poorly installed vapor barriers can be responsible for excessive heat loss through house walls, as well as for damaging moisture buildup in the walls. Computer analysis of data gathered in the winter of 1965-66 showed that broken vapor barriers permitted up to twice as much heat loss as did identical wall panels with intact barriers.

Accelerated Testing of Glue Bonds

A new technique for evaluating adhesives rapidly under simulated service conditions, described in the 1965 Annual Report, was used to study the effect of environmental conditions on degradation of urea-type adhesives. Moisture was shown to control the rate of shear-strength loss in plywood specimens at a given temperature. Specimens in a completely dry environment were affected primarily by strength loss in the wood. The rate of loss quickened as more moisture was introduced at various temperatures. The urea adhesive reacted with water to form formaldehyde, indicating hydrolytic breakdown of the resin polymer. Oxygen in the air, however, did not significantly degrade the adhesive.

Accelerated tests for rapid screening of different urea resin formulations or for control of product quality are possible applications of these findings. For example, a water-soaking test at 60° C. would accelerate strength loss considerably and at the same time permit detection of small differences in bond quality between different adhesive formulations.

Methods have been developed to measure such mechanical properties of adhesives as elastic modulus, creep, yield stress, and relaxation under load. Free films cast from the adhesives are used for this work. Creep experiments have shown that emulsion glues such as the polyvinyl resins yield films that stretch considerably more in a given time under constant load than do resorcinol films. New thermosetting polyvinyls were improved in this property, although they too were materially affected by changes in moisture content. A relative humidity increase from 30 to 65 percent caused the creep rate to increase a thousandfold. This finding suggests that these test methods have great promise for evaluating different adhesive formulations.

Technician Robert Lulling lowers specimens of plywood overlaid with poylvinyl fluoride into water tank for soaking-drying cyclic test. M 131 690-1

Preservative Effects on Glue Lines

The best synthetic resin glues withstand effects of preservatives just as well as they do moisture, results of 20-year exposures to outdoor service conditions have demonstrated. Resorcinols, phenol-resorcinols, and melamines were used to laminate beam specimens of red oak, hard maple, southern pine, and Douglas-fir for the long-term exposure tests. The beams were pressure-treated with eight different preservatives before exposure. None showed any deteriorating effect on the glue.

PVF Overlays on Pilot Plant

The polyvinyl fluoride outer skin of the new pilot plant under construction for research in wood fiber products was given an accelerated evaluation in the laboratory even as the stressed-skin plywood panels on which it was commercially bonded were installed during the summer. Similar plywood specimens had been under observation for 2 years while weathering at the Madison exposure site, but specimens taken directly from panels made for the construction were given accelerated cyclic soaking-drying tests. The results were satisfactory, indicating excellent stability of the skin and the adhesive bond fixing it to the Douglas-fir plywood. Results will be compared with actual long-time performance of the skin on the new building.

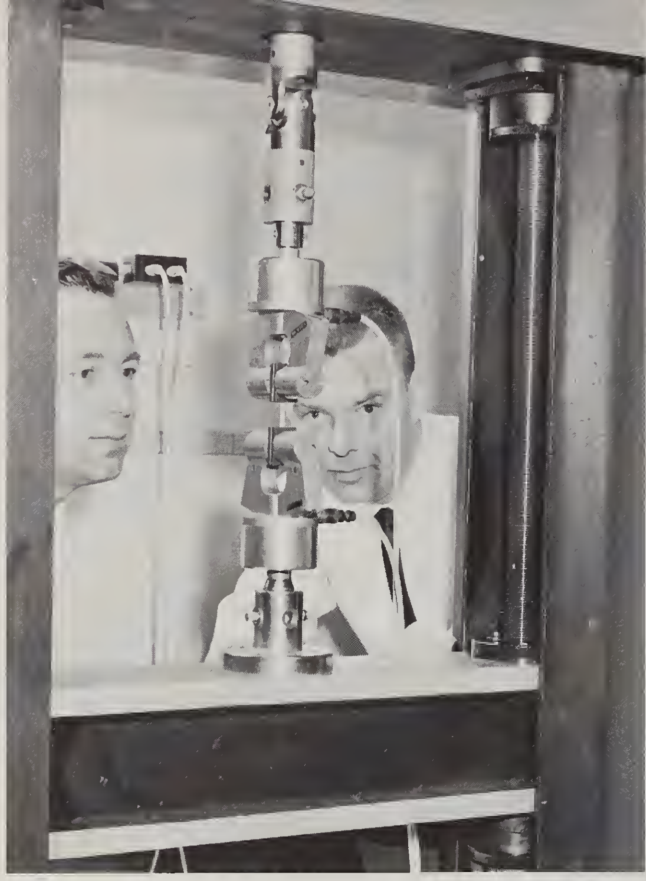
Gluing Fireproofed Wood

Available fire-retardant chemicals can effectively lower the combustibility of wood and make it acceptable for use where codes and other restrictions exclude untreated wood. Such chemicals, however, introduce other problems, such as slowing down the rate at which adhesives cure.

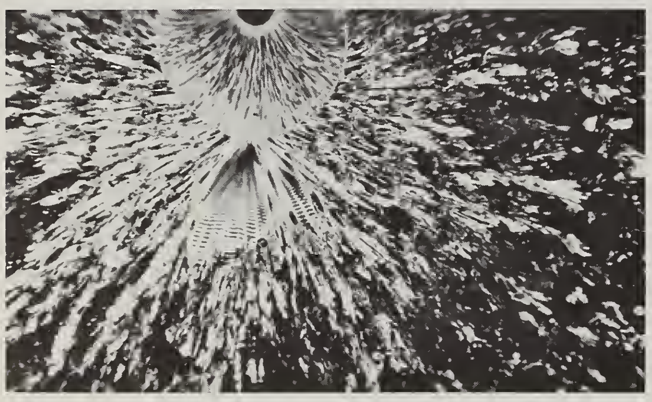
Experiments on the gluing of fire-retardant-treated wood demonstrated that either a longer curing time or higher curing temperatures are necessary than when untreated wood is used. These experiments involved the use of both southern pine treated with ammonium-salt fire retardants and Douglas-fir and hemlock treated with boric acid retardants.

Glue Bonds in Wood

The most difficult glue bond to make in wood is a simple butt joint between squared-off ends of two



Glued butt joint in slash pine specimen ⅛ inch square is loaded in tension by technician Lester Floeter, left, while Dr. John Quirk, forest products technologist, watches specimen. M 132 747



Lines of stress radiating explosively from a point of weakness create an intriguing pattern in this greatly enlarged photo of a glued butt joint broken by tensile force. Slash pine specimen was ⅛ inch square.

pieces. Where strength is needed, scarf joints or finger joints are used, because they bring more wood substance into direct contact with the adhesive. A new study of butt joint formation made by an FPL staff member in partial fulfillment of requirements for a Ph.D. at the University of Wisconsin indicates, however, that considerably more strength may be obtainable than has heretofore been thought practical. It was concluded that butt joints properly made are suitable where moderate strength is adequate, as in moldings and other long, unstressed millwork parts. Advantages are simplicity of joint, economy of material, and ease of machining and alinement.

Butt-joint strength was shown to be significantly increased in slash pine when an elastomer was blended with a rigid epoxy resin adhesive. With this modified adhesive, joints between springwood parts were consistently stronger than joints between summerwood parts. The relatively flexible springwood fibers are apparently better able to relieve stress concentrations than the stiff, heavy summerwood fibers.

In a butt joint, many cells are cut open, exposing the hollow interior or lumen. Bonds are therefore formed in two ways; between abutting surfaces of wall cross sections and by penetration into the cell cavity and adhesion to the lumen wall. Differences in strength between springwood and summerwood joints are attributed to bonds between abutting wall sections. Strength of bonds to lumen walls was strongly affected by the pot life of the adhesive mixture used; the fresher the adhesive, the better the bond.

More Durable Natural Finishes

Attempts to capture and preserve the natural beauty of wood with clear finishes on exterior parts of buildings and other structures have so far met with only indifferent success. The short life of such finishes and difficulties of renewal and maintenance have discouraged many users.

Basic research seeking to establish the causes of such premature failures and the resultant troubles has been conducted at FPL for some years in cooperation with the National Forest Products Association and the National Paint, Varnish, and Lacquer Association. Findings point to destruction of both the finish and the wood substrate by ultraviolet radiation in sunlight (see 1965 Annual Report).

One of the mechanisms of this destructive action on wood by sunlight has now been traced to formation of free radicals in wood. The existence of free radicals was uncovered by electron spin resonance spectroscopy. The free radicals then react with oxygen to form degradation products. Analysis also shows that the irradiated wood has become more soluble and has lost methoxyl groups, while carboxylic acid groups are formed in it.

From data on amounts of volatile products formed as wood degrades, a method was worked out for measuring the extent of such degradation. This permits comparisons of species for resistance to the degrading effects of irradiation. Redwood was found to degrade faster than yellow-poplar, which in turn degrades faster than Douglas-fir. Treatment of wood surfaces with an ultraviolet light absorber, dibenzoyl resorcinol, significantly reduced the quantities of degradation products formed.

Several experimental finishing systems designed

to protect wood from radiation are under test at exposure sites in Olustee, Fla., Saucier, Miss., and Olympia, Wash., as well as Madison, Wis. All are of the nonfilm-forming type and inhibit mildew formation. They include mercurial fungicide and chromate compounds, cobalt phosphate, dibenzoyl resorcinol, water-repellent preservatives with and without pigment, zinc and cobalt naphthenates, and an FPL natural stain formulation with reduced content of linseed oil and increased fungicide content. A survey is also being made of chemical treatments for wood surfaces that will stabilize wood against ultraviolet degradation and permit the use of transparent silicone and acrylic polymers as coatings.

Protection from Decay

A preservative treatment first developed at FPL a quarter century ago for fence posts may also be useful for marine piling. The process, called double diffusion, consists of soaking green wood in a water solution of first one and then another preservative salt. Alone, either salt would be easily leached out by rain, soil, water, or of course seawater. The two, however, react in the wood to form an insoluble compound. Southern pine fence posts so treated remain serviceable after 25 years under rigorous decay conditions in Mississippi.

The potential of the double-diffusion process for protecting piling from attack by limnoria, a marine wood destroyer that is common in warm-water harbors, has been demonstrated in experiments. This wood-boring crustacean extensively damages port facilities. After 7 years, piling specimens given a two-stage treatment with copper and arsenic salts followed by a creosote treatment remained free of attack. Control specimens treated only with creosote had meanwhile been seriously attacked within 44 months.

Experiments are now under way with wood piling treated successively with two reactive preservatives by pressure instead of the slower diffusion technique. A tentative specification covering combination treatments for marine piling has been drawn up for the American Wood-Preservers' Association.

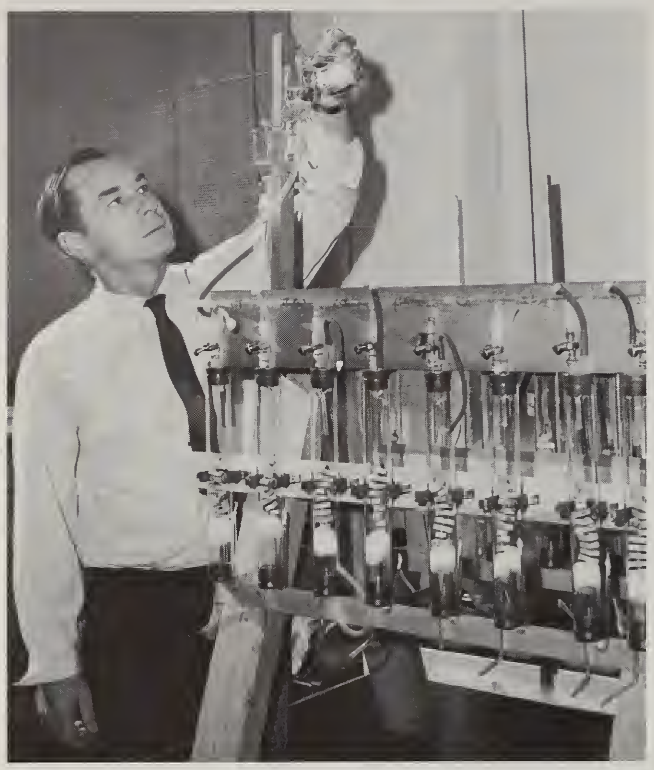
A decay-preventative treatment that is based on destruction of thiamine in wood rather than toxic chemicals continues to look promising. Thiamine is destroyed by treating the wood with ammonia gas at high temperatures. Fungi cannot survive on wood deficient in this vitamin, and the wood remains free of discoloring chemicals or oil solvents that interfere with paint.

Southern pine sapwood so treated has remained in good condition for 4 years while exposed to rigorous decay conditions at an exposure site near Saucier, Miss. Specimens were made of two pieces of the treated wood fastened together to form a typical porch-rail joint in which water can readily collect to stimulate fungus growth. Identical joints of untreated

Out with the old, in with the new. Above, FPL crew dismantles wood foundation still in good condition after 29 years while experimental house stood on it. Below, new foundation of wood and plywood treated with preservative is assembled for another experimental house. M 131 268
M 131 705-8

wood have meanwhile been destroyed by decay. A complication that had been anticipated — the recapture of thiamine by the wood — has so far not occurred, indicating that protective paint or water-repellent preservative may not be necessary.

Decay fungi that cause heavy losses to southern pine pulpwood chips stored outdoors have been isolated and identified. To do this, an apparatus was built that simulates conditions of temperature and moisture within a pile. The findings are being used to devise methods of protecting outdoor storage piles from decay losses. Identification of organisms found in a pulpmill pile of hardwood chips is under way. Cooperating in this work are a paper company and the Northeastern Forest Experiment Station.



Decay and staining organisms obtained from storage piles of pulpwood chips are studied by Pathologist Dr. Wallace Eslyn in apparatus he devised for culturing them.

M 131 657-10

Cultures of white rot fungi grown on lignin degradation products are examined by Rebecca Gettens, graduate pathology student, in search for enzyme systems that break lignin down.

M 132 657-7

Strategy of an attack on an isolated colony of termites in Ontario, Canada, during the summer of 1967 is plotted by Dr. Glenn Esenther, left, FPL entomologist, and David Gray, entomologist of the Canadian Forest Products Laboratory, Ottawa Branch.

M 131 854-10

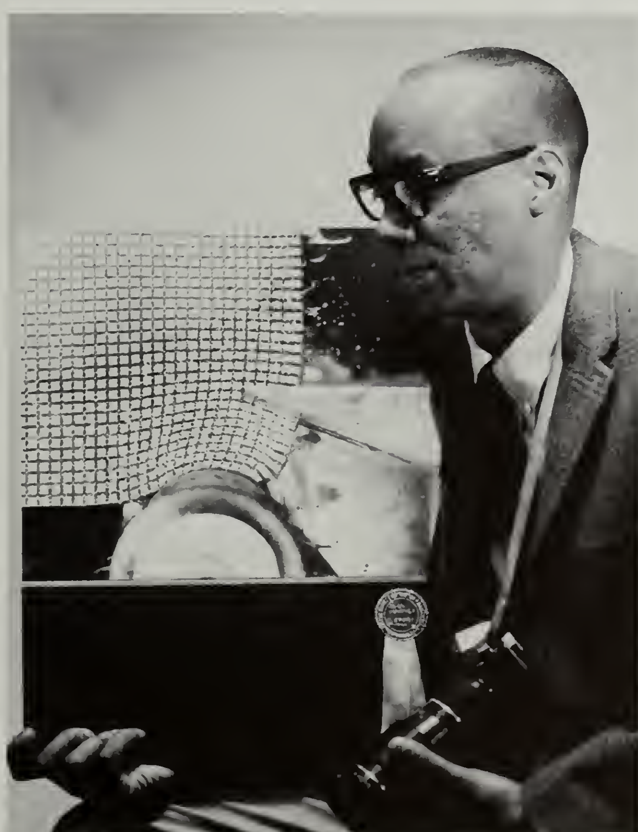
Basic research on the decay process has yielded further evidence of internal cell-wall penetration by the thread-like hyphae formed by decay fungi and which release rot-causing enzymes. Extraordinarily small hyphae of the so-called "white rot" class of fungi were found growing within the cell walls of wood specimens prepared for the microscope with special staining techniques. It was also observed that only the cellulose immediately adjacent to hyphae was being affected by enzymatic action.

How fungi break down the lignin in wood is also under study. Attempts to show directly that lignin is destroyed by enzymes that oxidize it have not been fruitful. In fact, the relatively few white rot fungi that do not produce oxidizing enzymes were found to thrive on lignin degradation products better than some that do produce them. An explanation was found in the fact that the oxidase producers actually convert phenolic lignin compounds to toxic thymoquinones that retard fungus growth. The fungi that do not produce these enzymes cannot convert the lignin to substances poisonous to them.

Potential Termite Controls

New knowledge of the life cycle of termite colonies has yielded promising suggestions for controlling these wood-destroying insects. Evidence shows that the destructive power of a colony fluctuates between egg hatchings, and that the colony may be especially susceptible to destruction when eggs are hatching.

It had been found in earlier studies that a termite bait containing both an insecticide and a previously discovered attractant tends to inhibit foraging by the insects (see 1965 Annual Report). Subsequent laboratory observations have suggested that such inhibitions may lethally disrupt development in a colony. A field study designed to tell whether termite infestations can be eradicated in this way has been begun in cooperation with the Canadian Forest Products Laboratory at an isolated termite-infested area in Ontario. The isolation helps to insure control of the experiment and evaluation of results.



The American Society for Testing and Materials awarded third prize in the black and white class, general photography division, of its annual meeting contest to this photograph by FPL photographer James K. Brooks. The photo is entitled, "Visual Observation of Compression and Shear During Timber Slicing." M 132 825

WOOD ENGINEERING RESEARCH

Engineering research has a key role in maintaining and expanding the usefulness of wood and wood-base materials in buildings, vehicles, containers, and other structures. Inadequate knowledge of wood's strength and related properties, coupled with inefficient methods of fabricating structural parts and building components, continues to cost users dearly. Yet the structural uses of wood — as lumber, millwork, plywood, hardboard, particle board, utility poles, piling, and the like—constitute its most important market. This multibillion-dollar market underlines the importance of getting the knowledge needed for more efficient utilization through research.

About a billion dollars' worth of structural lumber is produced annually. Present grading methods, either visual or mechanical, are only 50 percent efficient; that is, the lumber is so graded that, on the average, only half its load-carrying capacity can be safely utilized. An improvement in grading efficiency to 70 percent would be tantamount to a lumber cost saving of $200 million. FPL engineers consider this a reasonable and attainable goal of research on the nondestructive testing of wood.

Half a billion dollars' worth of insulating board, hardboard, and particle board is made each year, putting to better use some 2 million tons of woods and mill residues formerly discarded or burned for fuel. Yet the market could be greatly broadened — and much more residue utilized—if these materials could be more precisely manufactured to strength standards required for engineering design purposes.

From 1952 to 1962, the amount of lumber used per dwelling unit dropped from 10,000 to 8,200 board feet. This trend has prompted economists to predict a further decline to 7,100 feet in the year 2000. This is not necessarily bad—in fact, it can be beneficial if it derives from more efficient use of lumber. Moreover, some compensating increases are projected in the use of plywood and building boards, and population growth is expected to bring total lumber requirements well above existing consumption levels. These projections, however, assume technological advances in structural use of wood that can be attained only through successful research.

Packaging of goods for shipment and storage consumes 762 square feet of corrugated container board per capita annually. Elimination of manufacturing variables in container board could save $35 million a year in shipping costs by making possible lighter weight boxes. Fiberboard boxes with better stacking strength could save shippers $50 million annually in reduced warehousing damage, and better cushioning materials and designs could reduce damage claims by another $150 million a year. Yet the answer is not simply in more packaging; overpackaging is so common that it imposes a heavier economic loss than underpackaging. More precise engineering design of packages based on research promises enormous benefits.

Improved Strength Grading

One of the big gaps in our basic knowledge of wood strength and related properties is how each of the important structural properties is affected by knots, cross grain, and other defects. Ignorance of the specific effects in a structural element is compensated for in existing grading practices by large penalties against the average strength of straight-grained, blemish-free wood. In a particular instance, this ignorance has been in large part due to the inability heretofore to establish, for lack of reliable testing equipment, the tensile strength of wood. Tensile failure is often the first kind to occur in beams, truss diagonals, and other structural elements under bending loads.

A new FPL technique for tensile testing (see 1964 Annual Report) is helping to eliminate this problem. During 1966 a new tensile testing machine was put to use that permits testing members in a horizontal position. A large sample of southern pine dimension lumber, 2 by 4, 2 by 6, and 2 by 8 inches in cross section and containing knots, cross grain, bow, crook, and other observable defects, was tested in this equipment. The extent and location of all defects were noted, and the region where it was anticipated that each piece would break under tensile load was predicted. The majority so far tested have failed where predicted.

The data thus obtained will be analyzed statistically to establish a quantitative relation between defects and tensile strength. This information should prove highly useful in developing improved techniques for both visual and machine grading of lumber.

The same sample of southern pine lumber was first measured for flatwise modulus of elasticity over a 48-inch span at various locations along the length of the pieces. Modulus of elasticity is an indicator of stiffness and as such is the basis for one method of mechanical stress grading.

The 48-inch span is approximately that used in mechanical grading machines. Results are being related to the tensile strength data for the same pieces. Early indications are that short-span modulus of elasticity accounts for up to 60 percent of the variation in tensile strength; over-all modulus of elasticity accounts for only 43 percent.

The early results also suggest that, the more defective the piece, the greater the correlation between short-span modulus of elasticity and tensile strength.

Tensile failure produced in a joist by new FPL tension testing machine is inspected by D. V. Doyle, FPL research engineer. New type of end grip devised at FPL makes possible more accurate determination of tensile strength of lumber. M 132 102

Vibrating reed of compression calibrating ring is watched by technician A. J. Motelet as he checks out a testing machine for accuracy. Ring itself was calibrated by U.S. Bureau of Standards to relate amount of deflection to compressive load imposed on it. Calibration values are compared to dial readings of machine to check for errors. M 130 781

This work is being expanded to include density and other features with size and location of knots and other defects in developing means for improved predictability of tensile strength. The results are expected to have direct bearing on both visual and machine methods of grading lumber for strength.

Pin-pointing the performance of visual grading was a study completed on the strength of southern pine lumber so graded. The study showed that such grading is only 48 percent efficient for bending uses and 43 percent efficient for compression. This inefficiency arises because many pieces in a grade are well above the stress ratings for the grade. They are only partly offset by a few pieces that fall below the assigned values. Visual grading providing for average quality material simply cannot discriminate closely enough between weak and strong pieces.

In another study, test data on dimension lumber are being analyzed to learn how apparent modulus of elasticity measured over full span in bending is related to the visually obtained bending strength ratio. This work is being done at the request of Subcommittee I, Lumber, of ASTM Committee D-7 on Wood. Several laboratories supplied the data, hence differences involving such things as species, moisture content, size of pieces tested, and testing geometry must be resolved. The object is to establish whether modulus of elasticity can be treated as a function of grade in future lumber standards and how closely values for it obtained by visual and machine grading are correlated. That there is a correlation between modulus of elasticity and strength ratio has been established; the exact statistical significance, however, remains to be ascertained.

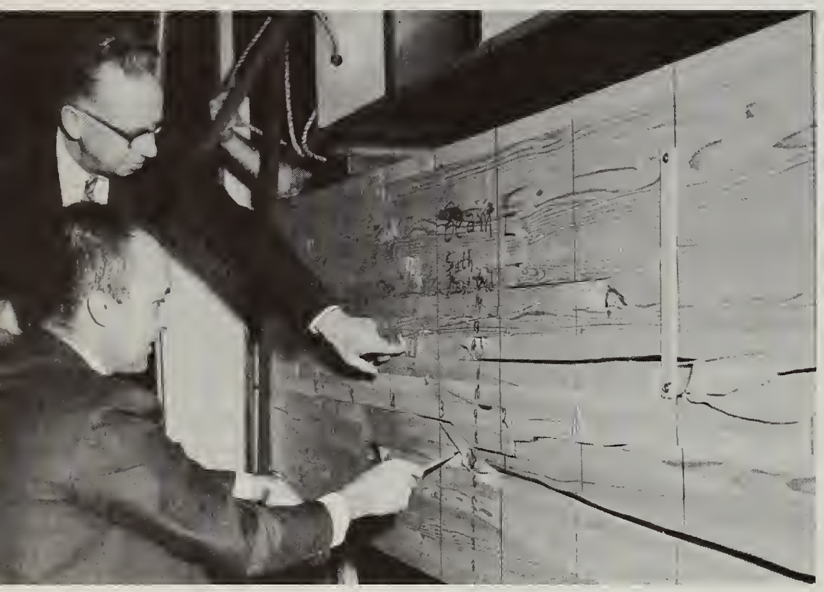
Beam Size Effect on Strength

The research on effects of knots and other defects on tensile strength of wood has a direct bearing on the design of laminated beams. For some years engineers have used a formula based on research on beams up to 16 inches deep.

Many structures are now designed for beams much deeper and longer. A new design theory, based on a "weakest link" concept, has been developed by FPL engineers (see 1965 Annual Report). During 1966, this theory was verified with bending tests of beams 50 feet long and 31½ inches deep. The theory established within 2 percent the loads obtained on beams made of clear lumber. Similar beams made of the L3 (lowest) laminating grade of Douglas-fir failed in tensile laminations at only 55 to 78 percent of the design load as calculated by the old formula based on the ratio of knotty to gross cross section.

Since laminated beams 5 feet and more in depth and over 100 feet long are now commonly made, the need for closer assessment of the effects of knots and cross grain becomes clear. This is emphasized by a finding from other experiments that beams made of knotty lumber can carry markedly higher loads if

In experiment to determine size effect on beam strength, one of largest laminated wood beams ever tested is subjected to compressive load at the Association of American Railroads Research Laboratory. Beam was 50 feet long by 31½ inches deep, 9 inches wide. M 130 601



Fractures originating at knots in beam loaded to failure in bending are examined by, foreground, Billy Bohannan, FPL research engineer, and Freeman Drew, structures research engineer at Association of American Railroads Research Laboratory. M 130 611

the outermost tensile lamination is made of clear, straight-grained lumber.

Tapered laminated beams—beams of largest cross section at either end or somewhere between — have long presented design problems. A new approximate mathematical analysis was developed to determine the stresses (normal, vertical, and shear) in beams of uniformly varying cross section. This analysis has been experimentally verified for tapered and haunched beams.

Prestressed Laminated Beams

Prestressing of laminated beams (see 1964 and 1965 Annual Reports) continues to show promise. Cable-stressed beams after some 2 years of continuous loading have not deflected any more than control beams not prestressed. This indicates that there has been no appreciable loss in the compressive prestress attributable to the creep characteristics of the wood.

A similar long-time loading study of beams prestressed by another method — a steel plate glued to the outermost wood tensile lamination—is now under way at Oregon State University under contract with FPL. Conclusive results are not yet available.

Fastenings Research

An investigation of the force necessary to embed heads of bolts and screws in wood was conducted for the Navy Bureau of Ships to aid in design of wood and plywood compartment bulkheads. This force was found to be at least 1,000 pounds per inch of head or washer perimeter for Douglas-fir plywood and southern pine and Douglas-fir lumber. The data are applicable to the design of anchorage for any structure exposed to wind, blast, and earthquake loads.

A study of load distribution among bolts of a multiple-bolt joint in heavy timber construction showed that division of load is very dependent on bolt spacing and the extension stiffness of the members being joined. Where bolts are equally spaced in a single row, load is carried primarily by the first two or three.

Hawaiian Species Properties

Continuing the evaluation program for Hawaii-grown species, FPL engineers determined basic strength properties of two more species, blackbutt eucalyptus and Norfolk-Island-pine. Both are plantation-grown imports from Australia. Blackbutt eucalyptus is a heavy wood with high shrinkage properties. It has high bending and compressive properties and is exceedingly hard and stiff. Norfolk-Island-pine is a moderately heavy wood and has properties somewhat comparable with those of intermediate-type Douglas-fir.

Density-Strength Relations

The extensive density survey conducted during the past several years on standing southern pine timber (see 1962 and 1963 Annual Reports) includes an evaluation of the specific gravity data obtained as an indicator of strength and related properties. In an additional sample, mechanical properties and specific gravity have been measured on the same specimens of slash pine to provide good regressions.

The Phase IV evaluation will be continued next year on additional commercially important species.

Design Data for Hardboard

Completion of most aspects of a basic investiga-

Bolstered on a truck trailer, the 29-year-old stressed-skin experimental house inches across an open field on its way to a site in the new Building Research Park. At right is a pole and slant-leg rigid frame building under construction, and in background are the main FPL building and new wood fiber products laboratory and pilot plant. M 131 257-10

tion to establish hardboard design stresses has involved more than 6 years of FPL research. Only creep resistance and a study of fatigue resistance, both long-time in nature, remain to be concluded.

The next step, now being examined, involves finding means of controlling quality in production. One proposed approach is to investigate the relation between elastic and strength properties. The correlation may be different for different commercial products, but there appears to be a good chance that any production run can be classified into groups with prescribed "go — no go" limits for a stress grade of material.

Building Board Insulation Values

Experimental evaluations of hardboards, building fiberboards, and particle boards for thermal conductivity have made possible valuable design information for engineers and architects concerned with heating and air conditioning problems. Basic design curves relating density to conductivity were developed from evaluations of specially made board materials containing no additives other than resin binder. The conductivity values for commercial products containing various additives were plotted on the same density-conductivity parameters. These values coincided more or less closely with the basic ones used to establish the curves, depending on additive content.

The thermal conductivity values were established primarily for calculating heat flow in buildings, based on a mean temperature of 75° F. Correction factors were also developed, however, for the board materials at other mean temperatures.

Housing Research

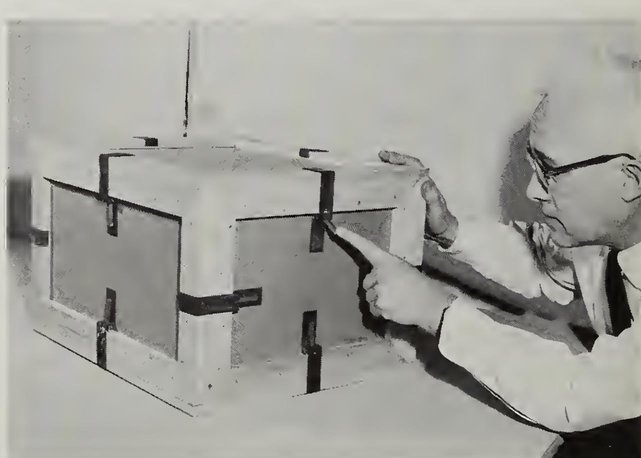
Development of the Nu-Frame design of house construction, featuring five basic components (see 1965 Annual Report), excited wide industry interest when announced last year. During the year, construction of components for a full-scale house was begun and the foundation and subfloor built. Included in the foundation is another experimental feature, a preservative-treated wood and plywood foundation wall. The subfloor includes component plywood-lumber sections of several designs to experiment with several species of wood and thicknesses and sizes of material. The superstructure will be erected during 1967 to begin a long-time evaluation of structural capabilities.

The Nu-Frame house will not, however, be the first structure in the new Building Research Park on the Laboratory grounds. The first was a pole-frame building with several slant-leg rigid frames at its midsection and a trussed roof (see 1965 Annual Report). And last summer the 29-year-old one-story stressed-skin prefabricated house was moved from its long-time location just north of the main Laboratory building to the Research Park. It survived the move over rough ground with little damage. Parts of its original wooden foundation were retained for strength tests.

Dual-chord truss is inspected by FPL carpenter C. J. Rohovetz as he lifts it from assembly jig. Diagonals and gussets are sandwiched between double chords. M 132 394-8

Polyvinyl fluoride film is glued to lumber-plywood base of roofing component produced in FPL shops for use in Nu-Frame house to be erected in 1967. M 132 394-4

New box assembling device for which public use patent was issued is demonstrated by inventor Robert S. Kurtenacker, FPL packaging research engineer. M 133 333



Package Cushioning

The damage and loss claims filed with carriers of goods, estimated at nearly $150 million a year, are in some part due to inadequate cushioning. The other

side of the coin, however, raises the question, how much excessive packaging is used because of ignorance of true needs? The cost of superfluous packaging could exceed that of damage to goods attributable to inadequate packaging. Both kinds of loss stem from the same lack of knowledge about cushioning requirements.

Research to supply answers is under way. In cooperation with Air Force packaging officials, various types of cushioning materials have been evaluated in terms of their resistance to dynamic impacts and energy absorption characteristics. Recent work in this area has developed useful data on the cushioning properties of corrugated fiberboard pads one to five layers thick. Findings indicate that use can be made of computer techniques to evaluate the almost limitless number of combinations of materials, flute configurations, and layer orientations possible in such built-up pads.

Better understanding of the damping properties of cushioning materials was obtained in a basic study of the principles involved. Basic kinds of cushioning materials were determined to be (1), closed cell, which undergoes negligible compression set under impact; (2) open cell, also taking negligible set; and (3) open cell-types taking relatively large compression set. Mechanisms whereby energy is absorbed were determined as (1) storage of static energy; (2) dissipation of energy by entrapped air, the molecular kinetic energy of which is increased momentarily thereby, with accompanying temperature increase of about 100° C.; and (3) dissipation of energy by permanent deformation of the cushion.

The container also absorbs shipping and handling shock forces. Thus, both the container and the cushioning inside it function as a unit in protecting the contents. The "container effect" has been determined by comparing peak-acceleration-static-stress curves of the complete cushioned pack with corresponding curves for the cushion only. A similar evaluation of the "container effect" is obtained by comparing the shock spectrum for the package drop with the shock spectrum for the cushion only. The shock spectrum depicts the damage potential of the given shock in terms of a plot of peak response versus resonant frequency. The results indicate that the container actually may detract from the protection efficiency of the cushion under certain conditions. Therefore the combination of packaged item, cushion, and container must be evaluated.

A study of the effect of dynamic loading conditions typical of the forces met in transportation is being conducted in cooperation with the Fibre Box Association. Laboratory conditions simulating shipping forces are being employed. Preliminary results indicate that the load a container can safely support under such dynamic conditions is much less than it can support under the static storage conditions of, for example, a warehouse.

Componentized system of house construction developed by FPL engineer L. O. Anderson was exhibited to Building Research Institute meeting in Washington, D.C. Here Sharon Peterson, FPL secretary, admires model. M 132 220

WOOD FIBER PRODUCTS RESEARCH

Our national appetite for paper and paperboard products hit an all-time high in 1966. We consumed 530 pounds per capita—more than a quarter ton for each man, woman, and child—52 million tons in all. And the hunger grows. In the year 2000, economists expect that the national consumption rate will be 711 pounds per person—and there will be 325 million persons. To meet that demand, domestic mills will have to turn out 108.3 million tons, with imports supplying 7.2 million more — altogether, more than twice the record consumption of 1966.

The question inevitably arises: How to satisfy this constantly mounting hunger during the remaining third of the twentieth century while building timber resources for even greater demands to come?

Two main solutions are obvious: greater fiber production per acre, and more efficient utilization of available fiber. Utilization research has a key role in each. It must specify fiber requirements and qualities for the geneticist and grower of pulpwood; and it must find the improved processes needed to get more and better products from available fiber — reclaimed as well as new.

Fiber production is an aspect of wood quality research discussed elsewhere in this report.

FPL research on utilization of available wood fiber is focused on these objectives: (1) the broadest possible utilization of species and qualities of raw material; (2) new and improved processes of pulping to increase yield and efficiency; (3) new and improved processes of fiber sheet formation to enhance production efficiency and product utility; and (4) basic knowledge of wood fiber structure, fiber bonding mechanisms, determinants of pulp and paper properties, and related subjects, better understanding of which is essential for continued progress in applied research and product and process development.

During 1966, typical research achievements included:

1. Experiments that demonstrated the practicality of making southern pine sulfite pulp by the magnesium bisulfite process, thereby meeting a need for such pulps, which are adequate for certain grades of paper.

2. A bleaching process for whitening pulp made from reclaimed brown kraft container board was shown to have excellent economic possibilities. The bleached pulp can be made for an estimated $84 a ton, compared with the current market price of about $135. A company is planning to build a mill in the South, and a Lake States mill is considering the process.

3. A process for recovery of pulping chemicals from the smelt of burned spent pulping liquor of the neutral sulfite semichemical process gives strong promise of reducing pollution of air and water because of its economic advantages, particularly with regard to reduced capital costs.

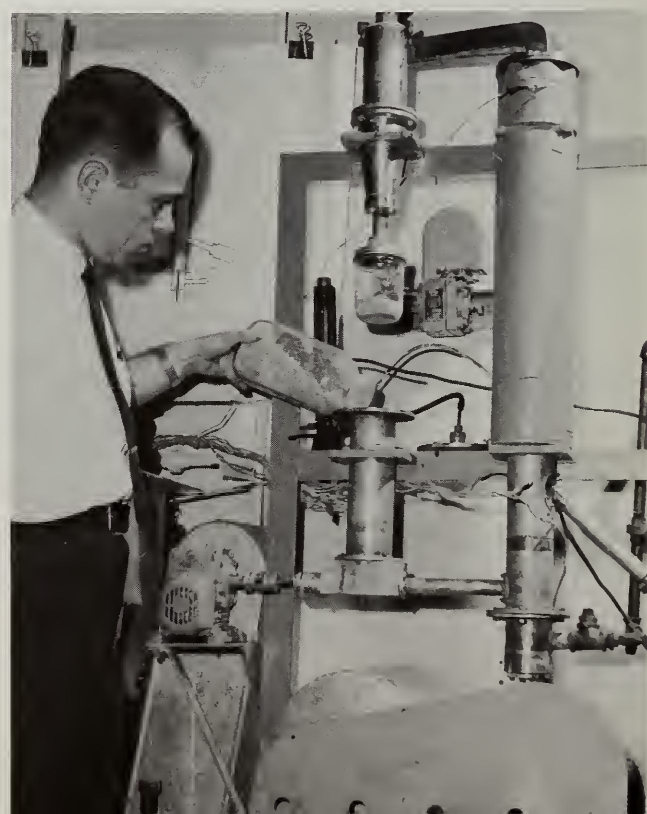
4. Research on effect of restraint during drying has shown that for each 1 percent reduction in shrinkage, edgewise compressive strength of paper is increased 10 percent. This finding has economic significance to the container industry, where compressive strength is often important, since it provides an increase in strength along with lower raw material costs.

NSSC Chemical Recovery Process

A new method of recovering chemicals used in neutral sulfite semichemical pulping demonstrated high promise in small-scale experiments. Among its advantages are low capital investment in the necessary equipment compared with existing soda-base recovery methods; use in conjunction with kraft recovery furnaces; and elimination of pollution as well as recapture of valuable chemicals.

The process consists of direct oxidation of the smelt obtained by evaporating and burning NSSC liquors in the same kind of furnace used for kraft spent liquor. Oxidation is done by feeding the smelt continuously into a fluidized bed reactor into which an air-moisture mixture is simultaneously introduced. Up to 80 percent of the sodium sulfide in the smelt is converted to sodium sulfite using favorable

Chemical engineer James Rice checks out apparatus for direct oxidation of neutral sulfite semichemical smelt to recover sodium sulfite pulping chemical. M 132 742-7



temperatures and air-water mixtures. The balance of temperature and air-water is critical; process efficiency can be seriously lowered with inadequate controls, with the result that sodium sulfite yield is lowered and formation of thiosulfate, a chemical of no value in pulping, increases. A cyclone separator collects the small amount of dust escaping from the reactor.

Southern Pine Printing Papers

The need for softer, more flexible softwood fiber than is normally obtained from southern pine may well be met in part from small trees removed in thinning operations on pine plantations. These fibers are more comparable to those obtained from northern softwoods, and are necessary for certain papers, such as printing and tissue grades.

FPL researchers are investigating the practicality of utilizing the comparatively lightweight fibers obtained from plantation thinnings. Kraft pulps made from them are much like pulps of northern softwoods; that is, high in bursting and tensile strength but low in tear resistance.

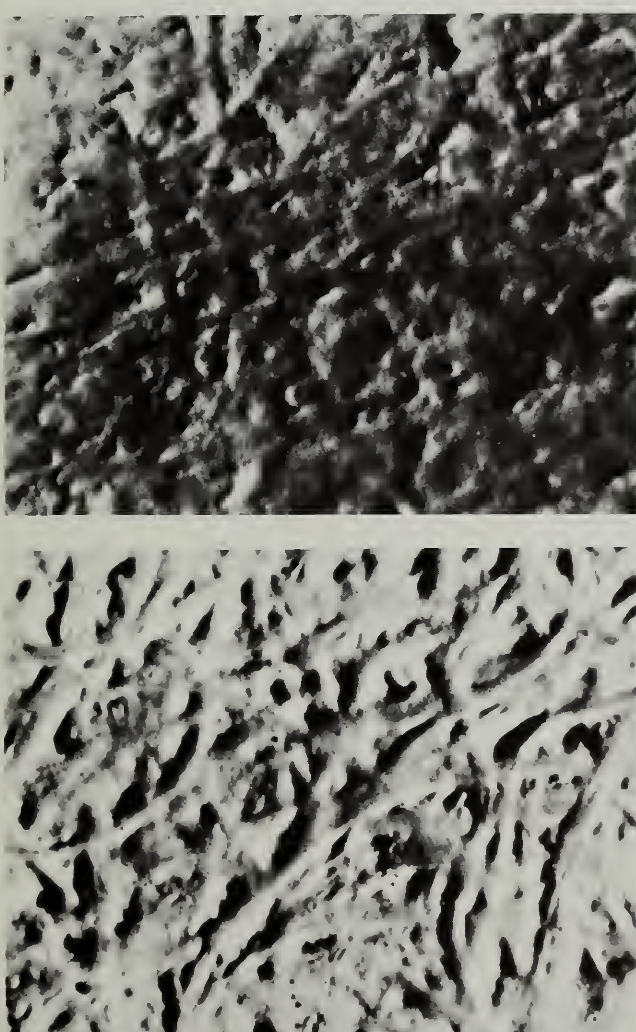
The wood from thinnings is also high in extractives content. This is largely responsible for relatively low pulp yields from a given quantity of wood. It also results in a high yield of tall oil, however, which in part offsets the low pulp yield.

Linerboards made from thinnings had higher bursting, tensile, and folding strength than liners of equal weight and thickness made from mature pine. On the other hand, multiwall sack paper made from mature wood had higher tearing strength and porosity than the paper made from the thinnings.

Another approach being commercially developed for production of coated printing papers is to separate summerwood from springwood fibers of mature wood by centrifugal force. In a cooperative investigation, FPL demonstrated that a paper containing 70 percent of springwood had a smoother, less porous surface after coating than did a paper with the reverse proportions. The springwood fibers collapsed much more than the summerwood fibers. The results indicate good possibilities of substantially improving printing quality of southern pine paper.

Southern Pine Bisulfite Pulps

Strong new possibilities of using southern pine to make such products as offset printing paper, book coating-base paper, writing papers, and toweling and facial tissues have been raised by new FPL experiments with magnesium bisulfite pulping of these species. Conventional sodium sulfite pulping widely



Surfaces of coated kraft papers made from southern pine, greatly magnified. Paper above contains 70 percent of springwood and 30 percent of summerwood fibers. Proportions are reversed in paper below. High proportion of more flexible springwood fibers results in smoother printing surface.

Aspen groundwood pulp produced on FPL stone grinder is sampled by Axel Hyttinen, research engineer, for experimental use in book paper furnish while technician Erwin Elert adds wood to grinding chamber.

used to make such grades of paper from northern softwoods is impractical with southern pines because extractives in the heartwood usually decompose the pulping liquor before digestion is completed. The new FPL experiments show that the magnesia-base pulping liquors are not prematurely decomposed. Experimental papers of these types were at least as good as commercial products except for slightly lower tear resistance in some instances.

To avoid papermaking troubles caused by pitch, which usually happen with pine pulps made by nonalkaline processes, the logs were stored for some months. As commonly occurs in the South, upon seasoning they become heavily discolored with blue stain. Nevertheless, the unbleached pulps were considerably brighter than kraft pulp. Fully bleached pulps of high brightness were obtained with a relatively inexpensive three-stage chlorine-hypochlorite treatment.

Another advantage of magnesium bisulfite pulping is that spent liquor can be burned economically after use to recover heat and chemical at a much lower cost than by kraft recovery processes. This is economically advantageous, especially for small mills.

Another use suggested by the relatively light color of the unbleached or semibleached bisulfite pulp is for the top sheet of kraft linerboard; it substantially improves the appearance.

Northern Softwood Kraft Pulps

A countertrend to the development of processes aimed at making southern pine pulps suitable for printing and tissue grades of paper is the mounting interest in kraft pulping of northern softwoods to obtain improved strength properties. The low density and relatively high cost of these species hitherto has discouraged expansion of pulp mills in the Lake States. Recent FPL experiments in cooperation with industry in this area are renewing interest in the northern softwoods.

These experiments have involved the pulping of northern softwoods individually and in various mixtures by the kraft process. The physical properties of all the pulps were superior, although pulp yield from several minor species, white-cedar, hemlock, and white pine, was somewhat low. Of special interest was the fact that pulp yield could be increased 15 to 20 percent with little or no loss in pulp strength, a factor which could offset some of the high cost of the wood. The superior bursting and tensile strength of the high-yield pulps makes them economically attractive for manufacture of certain high-tonnage brown papers and linerboard.

Appalachia Woods for Tissues

Results of papermaking experiments with sulfate pulps of Appalachian hardwoods — financed with funds from the Appalachia Regional Development Act of 1965 — show that production of sanitary tissues and toweling is technically feasible. The work was undertaken to aid in improving the economic condition of the region, which now has no mills producing such papers.

Boxboard Reclaimed for White Paper

Corrugated container scrap can be repulped and bleached to high-quality market pulp for white papers, FPL experiments in cooperation with a manufacturer demonstrated. The work was done on scrap consisting of linerboards made from Douglas-fir kraft and corrugated board made from mixed hardwoods. Some 3 million tons of container scrap made of various species are available annually, but reuse has been declining in recent years. Purpose of the work was to demonstrate both the technical and economic feasibility of reclaiming the fiber, much of which is destroyed.

The scrap was pulped with 12 percent caustic soda for 2 hours. Bleaching was done by a simple three-stage process, (1) calcium hypochlorite and chlorine, (2) sodium hydroxide and hypochlorite, and (3) calcium hypochlorite. This first- and second-stage oxidative technique, developed by FPL researchers, also greatly reduces the effluent color problem at bleach plants. Pulp yield was 70 percent of the weight of the unbleached scrap. Pulp quality was at least as good as that of bleached hardwood kraft pulp selling for $135 a ton. Production cost of the bleached pulp was $84 a ton based on a raw fiber cost of $46 (1.43 tons at $32), pulping and bleaching chemicals costing $15, and other costs totaling $23.

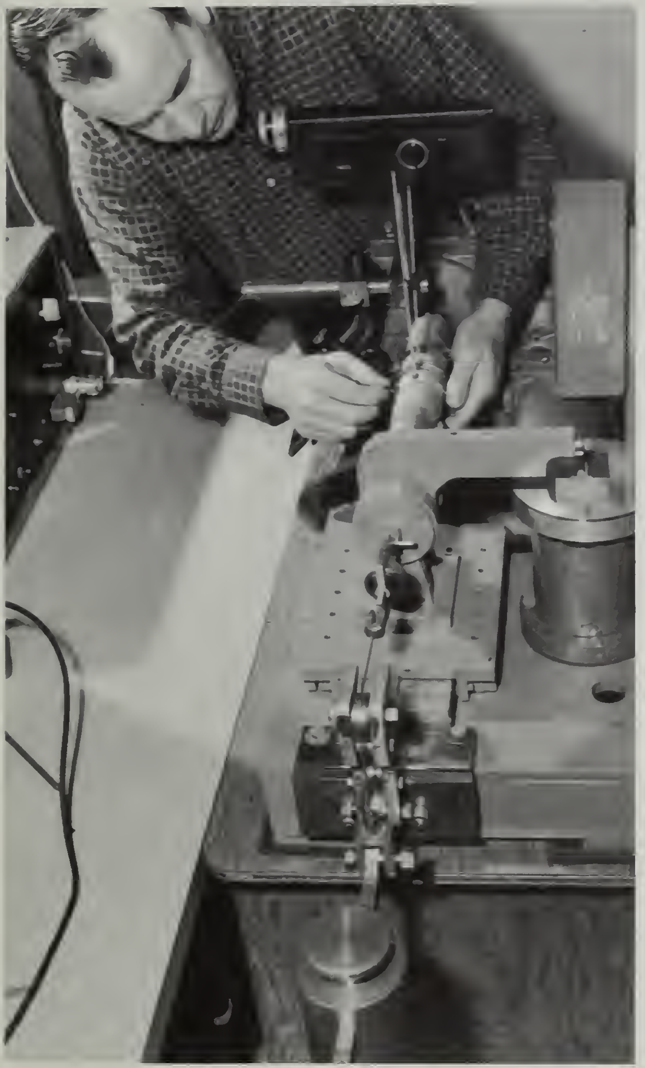
A Lake States mill is considering the process, and a mill is planned for construction in the South.

Applying Chemicals to Paperboard

Manufacturers of multi-ply paperboard (socalled cylinder board) incorporate chemicals to improve strength. Those whose board machines include size presses add chemicals—generally starch—to the surface of the sheet as it moves through the machine. Most producers, however, lack size presses and add chemical to the pulp furnish; inevitably, some is lost and further contaminates mill effluent.

Experiments at FPL showed it possible to apply chemical during boardmaking on machines without size presses. A mixture of cooked and uncooked starches is applied to one or more of the wet plies before they are combined. Most of the starch remains between the plies, indicating that the raw starch does not gelatinize until late in the drying process. This film contributes to the strength and stiffness of the board without any noticeable effect on the rate of drying.

Relatively simple equipment is needed to apply the starch mixture to the wet web while it is either on the cylinder or on the felt between the cylinders. Cost of this is minor compared to that of altering the drying and calender sections of a board machine to install a size press and additional dryers to remove the water added with the size.



Apparatus for biaxial tension test of paper is adjusted by Technician Roy Benson. M 132 748

Edgewise Shear Strength of Paper

Significant progress was made during 1966 on the study of basic strength properties of paper (see 1965 Annual Report). Not only was a method evolved for determining shear stress-strain characteristics in the plane of the sheet; analysis of shear data thus obtained led to the discovery that tensile stresses in shear specimens are higher than the values obtained by conventional tensile test methods.

The finding has significance in the design of products such as paper bags for loose granular materials. Such bags are multiaxially stressed in tension, a condition analogous to that revealed by the shear data, hence stronger in tension than conventional unidirectional tensile testing indicates.

The new shear-test method involves torsion of internally supported paper cylinders while a tensile end load is applied. It permits measurement of shear strength, stress at proportional limit, strain, and modulus. The method has direct application to design of containers for racking strength and to paperboard tubes or cores on which sheet materials are wound.

The discovery of unexpectedly high tensile stresses in paper throws new light on how paper fails in tension. When conventional tensile specimens are stressed in one direction (uniaxially), shear stresses induced at 45 degrees to the load direction exert a peeling action on the fiber-to-fiber bond. Bond failure weakens the sheet and precipitates tensile rupture. These early bond failures can be avoided, however, by reducing shear stresses that are usually present under tensile loading. This is done by applying stress in two directions (biaxially) normal to one another in the plane of the sheet. Tensile strength values up to 50 percent higher than unidirectional values are thus obtained. The significance of this in design of paper bags is readily apparent.

Two committees of the National Forest Products Association, the Committee on Technical Studies and the Technical Advisory Committee, met jointly at FPL September 28-30 for their annual research conference with staff members. Seated from left to right around the conference table are: D. St. George Anderson, MacMillan Bloedel Ltd., Vancouver, B.C.; W. Howard O'Brien, Southern Pine Association, New Orleans; T. K. May, Western Wood Products Association, Portland, Oreg.; R. A. Hewett, Canadian Wood Council, Ottawa, Ont.; Willard E. Pratt, Arcata Redwood Co., Arcata, Calif.; Neal Pinson, Western Wood Products Association, Portland; J. I. Zerbe, National Forest Products Association, Washington, D.C.; J. B. Albee, Maple Flooring Manufacturers Association, Oshkosh, Wis.; Alan D. Freas, assistant to the director, FPL; A. F. Muschler, Edward Hines Lumber Co., Chicago; J. G. Shope, NFPA, Washington, D.C.; Peter Johnson, California Redwood Association, San Francisco; G. F. Prange, NFPA, Washington, D.C.; R. H. Bescher, Koppers Co., Inc., Pittsburgh; Thomas R. Flint, American Plywood Association, Tacoma, Wash.; R. J. Hoyle, Potlatch Forests, Inc., Lewiston, Idaho; H. W. Eickner, FPL; L. Lee Rappleyea, California Redwood Association, San Francisco; C. B. Luding, Weyerhaeuser Co., Longview, Wash.; and Harold L. Mitchell, FPL.

WOOD CHEMISTRY RESEARCH

The complexity of wood's chemical composition and structure has long been recognized. Not so apparent, however, have been the pervasive effects of its chemical nature upon many everyday uses. Not only does wood afford a rich source of chemical products as yet only partially tapped; the behavior of wood in products is affected physico-chemically by environment, service conditions, moisture, preservatives, adhesives, finishes, and the various biochemical, pathological, and other processes that create and degenerate it. The role of the chemist in wood utilization research is therefore much broader than is generally recognized. FPL research is geared to this broader concept.

Yet even within the restricted popular concept of wood chemistry research there is a gigantic task to be done. Much wood is annually lost because existing techniques are, for one reason or another, inadequate. Stumps, branches, and tops of trees are left in the woods to rot or be burned. The equivalent of 2.8 billion board feet of lumber was classed as logging residues in 1962. Burning of residues results in the nuisance of smoke and in fire hazards. Saws, planers, and other woodworking machines left the equivalent of another 1.26 billion board feet in unused sawdust, slabs, edgings, veneer clippings, and the like. Cull trees standing in the forest on January 1, 1963, contained an estimated 54 billion cubic feet of sound wood for which there was no use; and millions more were, or should have been, removed as thinnings in young stands to promote growth.

Secondary manufacturing steps—furniture, house building, etc. — add more millions of units of wood annually to scrap heaps. Annually 8 million tons of bark are stripped from logs. The 1966 output of 47 million tons of paper and paperboard was accompanied by roughly the same amount of discarded wood substance; chemical processes dissolve lignin, hemicellulose, and extractives from the cellulose fiber to produce kraft and sulfite pulps.

Processes that can *economically* convert these staggering amounts of discarded wood and bark to useful things are wanting—and the lack of them constitutes an enormous challenge to chemists. The dimensions of the annual material drain delineate a wood utilization problem of mounting urgency as population rises and forest acreage shrinks.

Molasses for Stockfeed

Two decades ago, FPL scientists developed a process for hydrolyzing sawdust and other wood residues to produce sugar solutions that could be evaporated to molasses consistency for stockfeed. Experiments with cattle and hogs demonstrated good feed potential. Sharp declines in the price of other kinds of molasses, however, eroded the economic practicality of the process at the time.

The knowledge gained has proven of direct value in recent years for utilizing wood carbohydrates lost in the defiberizing of wood for hardboard manufacture. A major manufacturer of this product was confronted with a serious disposal and pollution problem. FPL chemists analyzed the carbohydrate material being discarded and found it to be quite similar to the wood sugars obtained by the FPL acid hydrolysis process. Data from the FPL feeding experiments and other information on nutritional value of the sugars encouraged the hardboard manufacturer to undertake production of a feed molasses produced by evaporating the effluent from the board process to the consistency of molasses.

The product is being sold in large volume for stockfeed. Consumption of all molasses types in 1966 was some 520 million gallons. Of this total, wood-sugar molasses accounted for 11 million gallons—all from the hardboard plant.

Analytical Method for Tall Oil

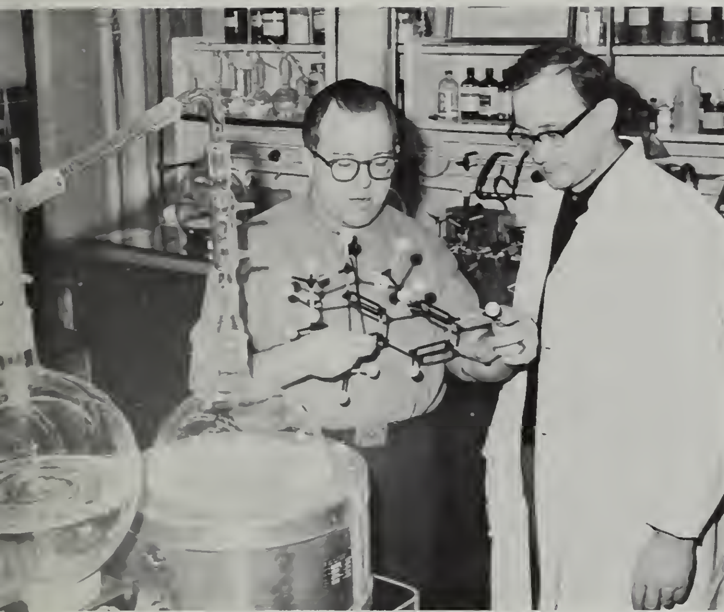
The mixture of resin acids, fatty acids, and other compounds obtained from the black liquor of the kraft pulping process and known as tall oil annually yields some $100 million worth of useful industrial chemicals, among them drying oils, alkyd resins, soaps, various lubricants, and emulsifiers. To aid industry in better recovery and utilization of this complex byproduct, a new and more precise method of quantitatively analyzing it has been developed by FPL chemists working in cooperation with the Pulp Chemicals Association. The gas chromatographic method gives quantitative data on the various acids present in the tall oil. It is expected to be useful also in analyzing extractives from fresh wood and those from stored wood, so that any changes occurring during storage can be traced.

Bark Extractives

Research on the chemical nature and constituents of bark over the past few years has yielded important fundamental information. A great number of chemicals have been separated and identified from softwood barks. Among them are 15 new representatives of the class of triterpenes, a widely distributed class of natural products. They are characterized by a feature extremely rare among natural terpenoids of this type — the presence of methoxyl groups in their molecules. A series of new diterpenes has also been found.

Staining Extractives in Wood

Working in cooperation with pathologists and silviculturists, FPL chemists have attacked staining



A model of the principal coloring matter that causes yellow stains in slippery elm is examined by Dr. John W. Rowe, in charge of FPL extractives research, and Dr. Michel Fracheboud, Swiss chemist spending a post-doctoral year at FPL for extractives study. Dr. Fracheboud elucidated the molecular structure.

Dr. John Harkin, lignin chemist, examines an intermediate in the synthesis of a lignin model compound for crystal formation.

problems in red oak lumber in experiments designed to identify the substances responsible for staining. This research has shown that tyloses — hairlike growths in the cell cavities—are rich in phenolic extractives, particularly gallic acid derivatives. While the work is primarily intended to aid manufacturers of flooring and furniture harassed by staining problems, it is also expected to be applicable to stains associated with pulpwood.

In a related study, a yellow coloring matter in red elm was identified as a new cadalenic sesquiterpene, 2-hydroxy-5-isopropyl-8-methyl-3-naphthaldehyde. This substance causes severe streaking problems in wood finishes. Identification can assist in developing treatments to counter the staining of finishes.

Lignin Research

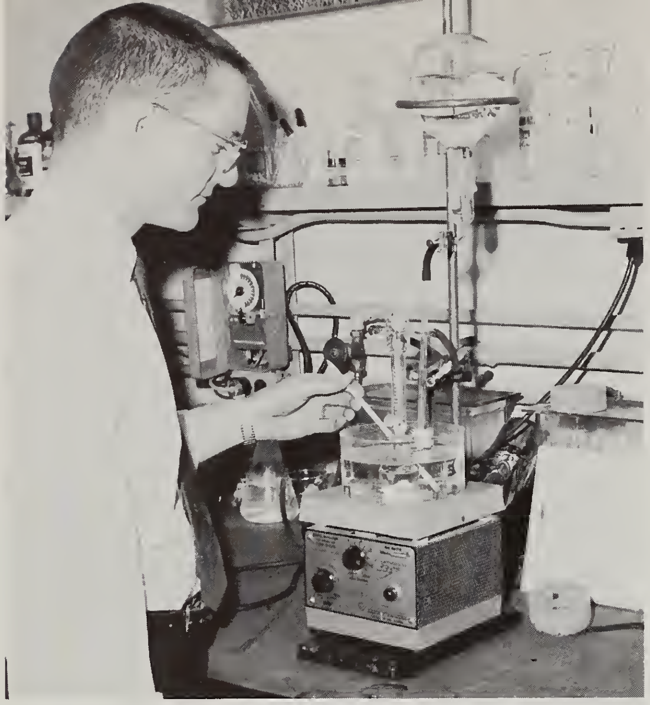
The complex picture of lignin structure that is slowly emerging from long and patient research, though still incomplete, is giving scientists renewed confidence that this plentiful but largely discarded component of wood can eventually be put to large-scale valuable uses.

One of the encouraging developments has been the discovery that many different parts of the massive lignin molecule are held together at certain junctures by relatively weak bonds, such as ether linkages. These bonds yield readily to certain treatments, notably acid or alkaline hydrolysis. Conventional pulping processes break these linkages. Unfortunately, some stronger bonds are substituted as a result of condensation reactions that accompany pulping. Consequently, the chemical makeup of lignin is radically changed by the time it emerges from the pulp digester. This greatly complicates the chemist's task of identifying the altered chemical structure and devising means of converting it to useful products.

Pulping processes that would cleave the lignin molecule into smaller polymers offer one obvious means of separating the lignin from the cellulose fraction in more readily usable forms. This is one of the goals of basic research seeking to establish the true molecular struture of lignin as it occurs in wood. FPL chemists have contributed to this knowledge by demonstrating, with model compounds synthesized to represent portions of the lignin model, how certain types of linkages could theoretically be formed as part of tree growth processes. Such work has shown that relatively strong biphenyl and diphenyl ether bonds play a prominent part in linking together various parts of the lignin molecule. Recent findings have, however, also suggested the probable presence of aldehyde and ester residues in lignin that will readily succumb to chemical attack.

Carbohydrate Research

In carbohydrate research, the mechanism of dehydration of sugars and wood carbohydrates is under study because of its importance from the standpoint of losses of cellulose during pulping processes in alkaline solution and in the production of potentially com-



Dr. Roger M. Rowell oxidizes meta saccharinic acid with nitric acid in experiment to check assumption that the end product of this reaction is identical to that produced by the alkaline treatment of hexuronic acid 3-deoxy-osones.

mercial products, such as furfural and 5-hydroxymethyl furfural, from wood carbohydrates. Chemical reactions were investigated by which dehydration products are obtained from hexuronic acids, which are constituents of wood carbohydrates. Hexuronic acids yield, in addition to furfural, two other important compounds, 5-formyl-2-furoic acid and reductic acid. Various hexuronic acids labeled with carbon-14 were used. It was concluded that the major reaction pathway involved the 3-deoxy-osones as chemical intermediates. The results were reported at an Amerian Chemical Society meeting.

The 3-deoxy-osones of D-galacturonic and D-glucuronic acid have now been synthesized in the laboratory by treating uronic acids with n-butyl amine, reacting with glacial acetic acid, and separating the products by paper chromatography. The 3-deoxy-osones thus obtained were treated with acid at high temperatures to ascertain whether they would perform as might be expected of true intermediates — that is, undergo the above dehydration reaction at enhanced rates compared to the parent uronic acid. The actual rate turned out to be some 12 times faster than furfural production from the starting uronic acid. Under different acid treatment conditions, they evolve carbon dioxide at twice the rate of the parent uronic acid. Reductic acid and 5-formyl-2-furoic acid were also formed at much faster rates. The evidence that these osones are accurate representations of intermediates is therefore substantial.

With these results of acid treatment, work has now turned to experiments with alkaline treatment of the osones. The reaction has been found to give rise to the meta saccharinic acids or trihydroxyadipic acids. The formation of meta saccharinic acid end groups on cellulose is known to stop the depolymerization of the cellulose molecule during alkaline pulping. This finding, therefore, encourages the hope that process changes may be found that interrupt the resultant destruction of cellulose by better control of alkaline pulping.

Penetrability of Wood Substance

Pores and other openings in the cells and cell walls of wood make possible its treatment with solutions of preservatives, fire retardants, pulping chemicals, and the like. FPL research is throwing new light on the molecular size limitations on the penetrating chemical to be used for such treatments. Carefully characterized polyethylene glycols of various molecular weights were used in cell wall penetrability experiments. The maximum molecular weight diffusable into green wood substance (green cell wall) was found to be that of PEG-3000, which is equivalent to a pore 20 Angstroms in radius. Treating solutions containing chemicals of greater molecular weights cannot penetrate wood substance. Conversely, the large molecules of natural lignin must be chemically divided until small enough to diffuse through these 20-Angstrom channels in order to separate them from the cellulose.

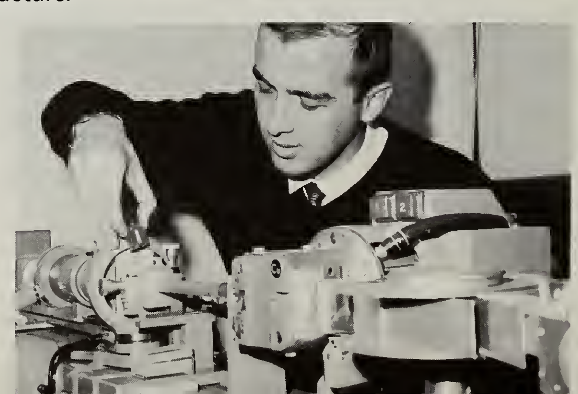
Density of Wood Substance

The generally accepted value for the density of wood substance, 1.46 grams per cubic centimeter, determined by FPL experiments some 30 years ago, has recently been questioned by investigators elsewhere. The old value had been determined in a displacement medium of helium gas. To check on its validity, experiments have been conducted with silicones of various molecular weights as displacement mediums in the expectation that, if cavities existed in the wood substance, the mediums of greater molecular weight would be excluded from openings of minimal size. Such an effect was not observed. The value of 1.46 was substantially confirmed.

X-Ray Diffraction

With new equipment, FPL investigators are conducting studies of the fine structure of wood as disclosed by the diffraction of X-rays passing through it. The equipment makes possible more precise measurements and study of the organization of molecules and crystallites within wood. It is also being adapted for rapid, low-cost analytical work with fire retardants, preservatives, and other chemicals used to treat wood.

Dr. Daniel Caulfield inserts specimen of cellulose in small-angle scattering goniometer for X-ray examination of its structure.



WOOD QUALITY RESEARCH

Wood quality research pervades the entire spectrum of wood's utility. In its broadest sense it includes the physiology and biochemistry of tissue formation in the tree and the fibrillar structure of the cell wall as well as the density of wood, its slope of grain, its texture, the occurrence of knots and other visible characteristics, and other gross features. These, in turn, influence such quality factors as strength, hardness, dimensional stability, machinability, finishing properties, ability to hold fastenings, and fiber and chemical content.

Logically, therefore, the many facets of wood quality research significantly affect the economics of forest products. How lumber grades out from the log is in large part determined by the operator's knowledge of log charateristics—how well he can detect signs of hidden knots and other defects and saw accordingly for maximum quality of production. How effectively timber managers can increase yield of wood without sacrificing quality depends greatly on knowledge of how quality is affected by management practices — thinning, pruning, fertilizing, even-age versus mixed-age stands, selective versus clear cutting, and the like. The tremendous quantities of wood used annually — 35 billion board feet of lumber, 13 billion square feet of plywood, 52 million tons of paper and paperboard, and additional millions of cords for cellulose products—emphatically stress the importance of efficient utilization.

The substantial contributions of wood quality research are perhaps more clearly perceived, however, in terms of what it can signify for the individual forester, mill owner, or manufacturer of wood products. A few such examples, based on recent FPL quality research, are:

1. Wood quality evaluation of hardwoods whose growth had been stimulated by nitrogen fertilization showed that machinability, a key criterion of quality for furniture, paneling, cabinetry, and the like, remains as good in fast-grown as in slow-grown hardwoods, including black walnut. Such growth speedup, therefore, can boost production per acre at no sacrifice of this critical quality factor.

2. An FPL improved sawing method raised production of No. 1 and better studs by 47 percent from butt logs of loblolly pine. The quality improvement was estimated to be worth about $10.50 per thousand feet of lumber. A mill producing 40,000 to 100,000 board feet a day would thereby net $50 to $500 more profit, depending on the mix of butt and upper logs being sawed.

3. The purchase of lumber for furniture part blanks and other "cuttings" of specified sizes is complicated by the immense variety of cutting sizes and qualities needed, the variation in sizes available from rough lumber depending on grade and the quality latitude within a single grade. Heretofore, experience has been the only guide to buyer and seller alike as to what may be expected from a given grade. A study of hard maple grades has shown that it is possible to determine by computer the yield of cuttings of any size and quality to be expected from a given grade. The expectation is based on careful workmanship by the sawyers. That full yields are not always achieved in the mill is demonstrated by a recent FPL study comparing mill production with a computer yield prediction. The computer had predicted a yield 12½ percent greater than was actually sawn out — a plain indication that greater yield should be possible.

4. Many defects, such as knots, are apparent in the growing tree. Some, however, show up only after the lumber has been cut. Such a down-grading characteristic is black stain in red oak, which is blamed for reducing much otherwise high-grade oak flooring to No. 1 or No. 2 Common. The cost to the flooring industry, estimated at $100,000 a week, is a valid measure of the need for research on the causes and control of such stains.

Warp in Lodgepole Pine Studs

Successful conclusion of the sawing study of loblolly pine logs (see 1965 Annual Report) and results of a preliminary evaluation of lodgepole pine have led to a comparable investigation of different sawing methods now under way on this western species. For this purpose, FPL personnel obtained nearly 700 logs from a mill at West Yellowstone, Mont., in 1966 and began sawing them into 2 by 4 stud material, marking each stud carefully as to location in the originating log, measuring it for accuracy of cut and any warp (deviation from straightness), then seasoning and remeasuring it, feeding the data to computers, and analyzing the results. The study is expected to continue through 1967.

Although lodgepole pine grows much more slowly than loblolly and therefore has much less juvenile wood around its pith, studs produced from this species also have a pronounced incidence of warp. How much warp-prone juvenile wood can be tolerated in a lodgepole pine 2 by 4 remains to be established. Likewise, the effect of compression wood on warping tendency of lodgepole pine studs must be clarified.

The FPL sawing method successful with lodgepole pine (see item 2 above) will be tried along with conventional sawing techniques on the lodgepole pine as a means of minimizing the warp effect of juvenile wood and compression wood.

Lodgepole pine logs shipped from mill at West Yellowstone, Mont., are unloaded at FPL. M 131 790-7

Hardwood Cutting Yields

The strong wave of industry interest stirred by last year's formal announcement of success in developing a computer program for predicting cutting yields from hard maple (see 1965 Annual Report) encouraged further development of the research to simplify its direct application to problems of buyers and sellers of hardwood lumber and dimension stock.

One important forward step was the discovery that computer predictions can be converted to chart forms from which cutting yields for a given grade can be read. It is believed that such charts can be devised for other hardwood species as well, to aid buyers and sellers in making accurate estimates of what to expect from a given grade and species in terms of cutting yields without resort to costly computers. A publication containing such charts for hard maple is expected to be published by FPL in 1967.

Data on hard maple cutting yields produced by computer are studied by Dr. George Englerth, technologist in charge of study, and Claudia Wodzinski, FPL mathematician. M 131 312

Black Stain in Red Oak

Research on the causes and possible control of black stain in red oak (see item 4 above) has uncovered three distinct types of dark discoloration in the apparently sound wood of both red and white oaks. One kind appears to originate in the living sapwood of standing trees, a second in the sapwood-heartwood boundary, and the third in the normal, fully developed heartwood.

Stains of the first type result from injuries to sapwood that appears physiologically normal. Common injuries include mechanical wounding, breakage or natural pruning of branches, insect boring, and infections by fungi and bacteria. If these injuries heal over, the resultant black stains will eventually become incorporated into the heartwood with subsequent tree growth.

Stains forming at the sapwood-heartwood boundary are generally not directly associated with obvious stem wounds, and quite often trees containing this type of stain are vigorous in external appearance and have clear merchantable stems. It appears that soil chemistry and possibly micro-organisms associated with the root system may be indirectly responsible for stain formation in the stem during the transition from sapwood to heartwood.

The third type has been traced to certain species of fungi that attack cells of normally colored, completely formed heartwood. The enzymes of these fungi apparently discolor normal heartwood extractives.

The stains in the living sapwood and fully formed heartwood are invariably associated with wounds or natural pruning. Surface indicators of the wounds or naturally pruned branches persist for many years, hence are warning signals that the wood underneath

may be discolored. Surface indicators of the stain in the sapwood-heartwood boundary, however, are nonexistent. Certain site conditions are being studied as possible causes, and therefore indicators, of this type of stain.

Walnut Growth-Quality Evaluation

Among our prized native hardwoods, all of which are becoming more scarce in sawlog and veneer sizes, walnut is perhaps the most sought — and among the scarcest. Top-quality walnut lumber brings $650 and more per thousand board feet at the sawmill. Industry concern about the mounting shortage has stimulated new plantings throughout the growth range. The keen interest in all aspects of walnut culture was expressed late in 1966 at a workshop at Carbondale, Ill., jointly sponsored by Southern Illinois University, the American Walnut Manufacturers Association, and the North Central Forest Experiment Station. At that workshop, available FPL knowledge on walnut growth-quality relationships was reported. The admittedly meager data indicated that fast-grown walnut was equal in machining quality to the more common forest-grown wood.

Machining, though important, is of course only one index of quality. Others, as reflected by grade and other specification requirements for various uses, are strength, color, hardness, dimensional stability, and figure. To one extent or another, all are believed controlled by genetic and silvicultural means. A thorough quality evaluation taking all these indices into consideration is now under way by FPL and the North Central Forest Experiment Station.

Aspects of this investigation will be (1) color-extractive-soil relationships, (2) anatomical shrinkage-specific gravity relationships, and (3) toughness-hardness and machining associations. Station personnel will select trees from northern Indiana, recognized as producing excellent walnut, and the Missouri Ozarks, a relatively poor growth area. In both areas, fast-growing and slow-growing trees from both good and poor sites will be chosen.

The second logs of these trees, cut 8 to 13 feet above the stump, will be shipped to FPL for the various evaluations, and soil in which each tree grew will be excavated for chemical and physical analysis.

Density Surveys

The monumental task of surveying the density of standing softwood timber in 21 States has been largely completed (see Annual Reports 1962-65) as originally projected. As a result, a quality index of most of our existing supplies of heavily used softwood species is available for the first time along with Forest Service Survey data on quantity. Nevertheless, some work is continuing, mainly on additional species and, where necessary, on additional samples for verification purposes (see additional information under Wood Engineering Research).

Only two States, South Carolina and Tennessee, remain to be surveyed for density of the four major southern pines, longleaf, shortleaf, loblolly, and slash. Expansion to include species other than those four was begun with Virginia pine, which is of major interest to the southern pine plywood industry in the Southeast. Sites in North Carolina, Virginia, Tennessee, and Alabama were sampled. A specific gravity correlation between the breast-height core and the whole tree was found to be higher than for any other species reported to date, 80 percent ($r = 0.8034$).

Two additional western species, Engelmann spruce and western redcedar, have also been sampled and analyzed. Statistical formulas for predicting tree specific gravity were developed and survey core data analyzed.

A special study designed to relate the specific gravity of Douglas-fir to site elevation and rainfall is being made. A dual linear micrometer technique involving diameter and wall thickness measurements of 479,100 cells was used to compute specific gravity of wood from 225 sample trees. Data are being statistically analyzed for their relationship to elevation and precipitation. This study was needed because the mountainous terrain of the growth region greatly complicates such statistical analyses compared with the relatively flat terrain of the South.

A special density survey of Maine softwoods, conducted with the cooperation of the Northeastern Forest Experiment Station, the University of Maine, and industry of that State, was completed with publication of a joint report that gives tree specific gravity equations for eight conifers. Of the eight, only red pine shows a clear pattern of decreasing specific gravity with height. For white pine, the trend is less striking, with a leveling off or even a slight upturn at the higher sample points in the trunk. Tamarack was most erratic, showing no consistent pattern. The specific gravity of red, black, and white spruce and eastern hemlock tended to drop and then increase with height. Ranges and averages of both core and whole-tree specific gravity were determined for both northern and southern growth plots.

Wisconsin plantation-grown red pine was also surveyed for specific gravity. The data furnished a better predictor of gravity than those obtained for forest-grown red pine in Maine. The Wisconsin trees were relatively young, which accounts in large part for the lower average specific gravity value, 0.304 compared to that of the Maine trees, 0.391.

Wood Identification Service

Requests for free wood identification service dropped in 1966 for the first time in some years. A total of 678 requests from outside government were received, and 2,650 specimens were identified. Respctive totals for 1965 were 747 and 3,013.

Wood and wood products submitted included ancient archeological artifacts, specimens associated with criminal investigations, and imports. Foreign

hardwoods, principally Latin American, predominated.

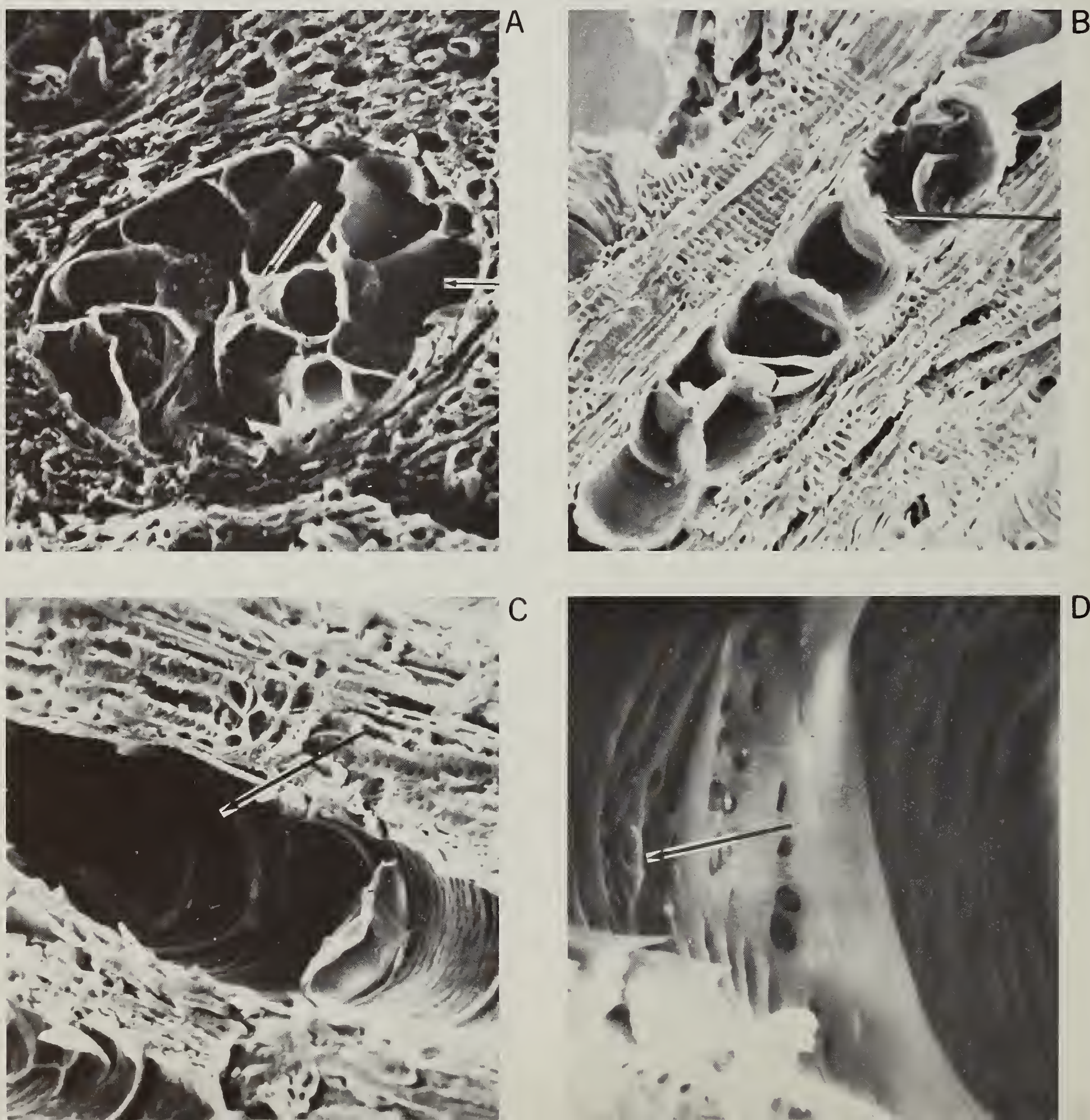
The U.S. Department of Agriculture extended for 2 years a Peruvian herbarium project under way since 1961 to identify and evaluate that Nation's woods. The work is financed with funds from the sale of agricultural surpluses to Peru. Two more new species were discovered, one of which was named by Dr. Louis O. Williams, curator of the Field Museum in Chicago, in honor of Dr. B. F. Kukachka, in charge of FPL wood identification. The new species is *Dacryodes kukachkana,* a wood somewhat resembling yellow birch in color but with a high silica content that is seriously damaging to cutting blades. Herbarium material of some 60 trees remains to be classified, and it appears likely that among them may be other new species.

Tylosis Formation

New knowledge of the development and structure of tyloses, balloon-like growths in the cells of hardwoods, is being gained by light and electron microscopic studies, including motion picture records. For this purpose, tylosis formation is being stimulated in red oak sapwood tissue by mechanical and chemical means because these growths do not usually occur naturally in this species. Some of the parenchyma or storage cells that adjoin the vessels appear to enlarge, and their protoplast projects into the vessel lumen through a number of pit cavities. These growths continue to enlarge until they fill considerable portions of the vessel cavity. The tyloses may develop from occasional pit-pairs only or from a great number of pit-pairs opening into a vessel. It appears unlikely that one tylosis develops from one parenchyma cell, but that more than one tylosis can develop.

The scanning electron microscope shows a reticulate (net-like) arrangement of pits in the walls of red oak vessels. This structure provides firm support

Electrongraphs taken with a scanning electron microscope dramatically bring out the fine structure of tyloses formed in red oak by artificial stimulation. **A,** transverse section of tyloses in a vessel, magnified about 1,100 diameters. Tylosis cross section measures about 300 microns. **B,** longitudinal section of tyloses in red oak vessel, magnified about 500 times; note balloon-like enlargement of tyloses, forming a stopple along entire length of vessel element. **C,** perforated wall of vessel, showing distinct reticulate (netlike) structure, magnified about 1,100 times. **D.** primary wall, showing entwined cellulosic elements magnified about 3,300 times.



for these large water-conducting tubes, particularly since portions of the primary wall that develop into perforations are not covered by secondary wall openings. This characteristic of the wall also would provide more area for the translocation of gases and fluids.

Coincident with findings concerning the pitting of the vessel wall, pitting was also detected in the tylosis wall. These pits are 1 to 2 microns in diameter. Intertylosic pits thus far have been found only in those areas where tyloses contact one another. This is thought to indicate that living substance must be associated with the two abutting walls. The tylosis wall seems thinner and more delicate than the cell-wall structure of other xylem elements. Under polarized light it appears to contain anisotropic substances. Chemical techniques are being used to isolate lignin and other constituents as a means of determining the chemical nature of the tylosis wall.

Fibril Angle in White Ash

The arrangement of cellulose microfibrils in cell walls is known to have pronounced effects on mechanical properties of wood, notably stiffness. These threadlike elements usually run parallel to the length of the cell, but orientation at any pronounced angle to the long axis reduces stiffness. Environmental factors are known to affect fibril orientation.

A new study is under way on fibril angle in white ash cell walls to establish its relationship to moderate and excessive soil moisture. Disks taken from one tree at different heights showed that the fibril angle decreases from the base upward. The angle was estimated by measuring, under polarized light, the deviation of the elongated pit apertures from the longitudinal axis of the cell. The trend was observed in every annual ring examined. From bark to pith at any height, however, no consistent trend was found; variation was ascribed to climate differences from year to year.

Aphid Effects on Wood Formation

Evidence that the properties of grand fir wood can be seriously altered by aphids on the living tree was uncovered in a study of affected wood. These insects penetrate the bark and feed on the cambium. Abnormalities of growth induced in cells formed during aphid attack produce wood with essentially the anatomy and properties of compression wood, which is weak, brashy, and excessively high in longitudinal shrinkage. The abnormal wood even looks much like compression wood.

Wood formed following aphid infestation has wider growth rings and more summerwood, is higher in specific gravity and lower in modulus of elasticity, and has greater longitudinal shrinkage than normal wood. Only maximum crushing strength appears unimpaired. Many cells have the circular cross section indicative of compression wood. A lower percentage of total sugars and a higher percentage of lignin were found in wood from infested trees.

Physiology of Wood Formation

A study launched several years ago to learn more of how wood cell formation is controlled and affected by nutrients has moved from its first exploratory phase involving techniques of culture into research on nutritional requirements, growth hormones needed, and physical needs for temperature, light, and humidity. The object is eventually to demonstrate the physiological mechanics, through manipulation of nutritional factors, that control the formation of specific cell types such as summerwood and springwood in the annual ring. This information can be used to develop silvicultural and management practices for improving wood quality.

In phase 1, techniques were worked out for continuing the growth of cambial tissue and wood cells detached from the living tree. During the study it was observed that, in addition to the known growth hormones, *myo* inositol was also shown to have growth control properties. In addition, analogues of *myo* inositol have been shown to be effective only if they are converted to the parent compound. This has been confirmed by studies with radioactive tracers, in cooperation with the University of Wisconsin. These studies point up the unique specificity of the *myo* form. Tests also show that the major portion present is operable in the free form in the growing cells. The findings contradict most of the published data on other herbaceous plant species and strongly indicate that *myo* inositol has an unknown role in the growth of woody plants.

Bordered Pit Membrane Pores

The size of pores in the membranes that block off bordered pits in cell walls largely determines the acceptable molecular size of preservative liquids and other chemicals for treatment of wood. A new technique for measuring pore size was devised by a University of Minnesota graduate student working under an FPL research grant. Measurements were made by passing suspensions of materials of several molecular sizes through wood from which air had been exhausted. Materials used were a ferric oxide aquasol consisting 99 percent of particles smaller than 8.6 millimicrons in diameter; a T_3 bacteriophage with a diameter of 47 millimicrons; and a CELO virus averaging 73 millimicrons in diameter.

Experiments demonstrated that membrane pores of coniferous tracheids exist in a characterizable distribution of sizes rather than a single narrow size class. White spruce used in the study definitely had larger pores than the Sitka spruce.

INFORMATION ACTIVITIES

Research developments at FPL generated unusually great interest during 1966 as news of them appeared in various media. The resultant heavy demand for FPL publications detailing the developments was typified by reader service requests forwarded to FPL by House and Home Magazine. A total of 1,320 requests were transmitted for copies of two research reports, FPL 31, "Guides to Improved Framed Walls for Houses," and FPL 47, "Development of an Improved System of Wood-Frame House Construction." Notices in other publications elicited many more requests for these and other publications, as well as inquiries about individual problems related to the subject matter of these reports.

Forty-six Forest Service research papers and notes were published by FPL during 1966. Another 68 articles and papers appeared in scientific, technical, and trade journals and Proceedings of meetings. A list is appended to this section. Fifty-nine news and feature stories dealing with research and related FPL activities were released to the technical, trade, and popular press, radio, and television.

Meetings

FPL was the meeting place of a number of important organizations in the forest products industries during 1966. The largest single gathering was a clinic attended by some 100 members of the National Wooden Pallet Manufacturers Association in July. In September about 75 technical leaders of government and industry attended the annual meeting of Committee D-7 on Wood of the American Society for Testing and Materials.

Other major group meetings included:

January: Research liaison committee of the National Woodwork Manufacturers Association.

February: Technical conference of Southern Pine Inspection Bureau.

March: Committee on Technical Studies, National Forest Products Manufacturers Association; forest fire research leaders of Forest Service.

April: Fiber and Particle Panel Products Liaison Committee.

May: Preservative Standards Committee of National Woodwork Manufacturers Association; Timber Task Force of Edison Electrical Institute; Research Committee, American Wood-Preservers' Institute.

June: Tall Oil Products Technical Committee, Pulp Chemicals Association; Task Group on Factory Primers, National Woodwork Manufacturers Association; Task Group of Committee D-7 on Wood, American Society for Testing and Materials.

August: Subcommittee on stresses in pilings, Committee D-7, American Society for Testing and Materials.

September: Committee on Technical Studies and Technical Advisory Committee, National Forest Products Association; Preservatives Subcommittee, National Woodwork Manufacturers Association; American Wood-Preservers' Association.

October: Central International Forest Insect and Disease Conference; Fiber and Particle Panel Products Liaison Committee.

November: Liaison Committee, American Paper Institute and Technical Association of the Pulp and Paper Industry.

Staff members attended meetings of scientific and technical groups both here and abroad. Alan D. Freas, Assistant to the Director, represented Director Edward G. Locke, Chairman of Section 41, Forest Products, International Union of Forestry Research Organizations, at a Section meeting in Paris, France. Other international conferences attended included a symposium on chemistry and rheology of water-soluble gums, London, England; The Canadian Wood Council Spring Conference, Ottawa; Second Canadian Wood Chemistry Symposium, Sainte Marguerite, Quebec; Fourth Symposium on Chemistry of Natural Products, Stockholm, Sweden; Mexican Technical Association of the Pulp and Paper Industry, Mexico City; Ninth International Congress, Federation of European Manufacturers of Corrugated Containers, Vienna, Austria.

Eight staff written papers were presented at the annual meeting of the Forest Products Research Society in Minneapolis. Four staff members presented papers at the fifty-first annual meeting of the Technical Association of the Pulp and Paper Industry in New York. Other national meetings at which FPL members presented research reports included the Building Research Institute Spring Conference; the Conference on the History of the Forest Products Industries at Harvard University; Committee on Fire Research, National Academy of Sciences - National Research Council; National Woodwork Association annual meeting, Minneapolis; and the Hardwood Plywood Manufacturers Association annual meeting at Ocho Rios, Jamaica. Two staff members addressed a Walnut Workshop at Carbondale, Ill., sponsored by the Forest Service, American Walnut Manufacturers Association, and Southern Illinois University.

Visitors

Fifty-eight Nations sent representatives to FPL during 1966 to help swell the number of consulting visitors to 3,834 out of a total of 11,709 of all types—scientists, educators, businessmen, students. The largest single representation was Canada's with 46; a close second was Argentina with 39.

Typical visitors from abroad included Dr. Y. C. Kim, National Industrial Research Institute, Seoul,

Korea; Sivasankaran Raghavan, Ministry of Food and Agriculture, New Delhi, India; Dr. Miroslav Mahdalik, Wood Research Institute, Bratislava, Czechoslovakia; Dr. Menachem Lewin, Director, Institute for Fibres and Forest Products Research, Jerusalem, Israel; Samwiri L. N. Serwanja, Principal Assistant Secretary, Office of the Prime Minister, Entebbe, Uganda; Abdossamad Darbani, Chief, Agriculture and Economics Statistics Division, Ministry of Agriculture, West Azerbaijan, Iran; Dr. Muharrem Miraboglu, Forestry Dean, Istanbul University, Turkey; John Beavon, Celcure Ltd., Kuala Lumpur, Malaysia; Malek Basbous, Director, Forest Service, Beirut, Lebanon; P. Gueneau, Tropical Forestry Technical Center, Tananarive, Malagasy Republic; and Prof. Fazliga Alikalfic, Rector, University of Sarajevo, Yugoslavia.

Among groups from foreign lands were 25 editors from Algeria, Iraq, Jordan, Lebanon, Libya, Morocco, Tunisia, United Arab Republic, and Yemen Arab Republic; and 15 members of the Japan Wood Technological Association, Tokyo.

Consulting visitors also came to FPL from 47 States and Puerto Rico.

Educational Activities

Three staff members were sent to universities for graduate study under the Government Employee Training Act. Eugene Wengert attended a summer session at Colorado State University, Fort Collins, for advanced meteorological studies. William E. Smith enrolled for graduate work in pulp and paper technology at North Carolina State University, Raleigh. Gilbert Comstock began advanced engineering and chemical studies at the State University of New York College of Forestry at Syracuse University.

Six University of Wisconsin students were employed in course-related research during the 1966-67 academic year.

From 20 States, 42 enrollees came for the 90th kiln drying demonstration conducted by FPL. In recent years these have been held annually in early spring. In 1966, however, the demonstration was repeated in November for 22 employees of the Forest Service, State forestry departments, and Extension Services of Land-Grant colleges. The Forest Service employees are in the Branch of State and Private Forestry. The demonstration was part of their training for a new technological service to forest industries.

Eight graduate students conducted research at various institutions with the support of FPL grants of Whitten Act funds. A University of Minnesota student continued his study of factors involving initial infection of wood by fungi; another concluded work in the size and distribution of pit membrane openings in partial satisfaction of Ph.D. requirements.

At the State University of New York College of Forestry, Syracuse University, one student continued work on the effects of transverse stress on equilibrium moisture content of wood, and another on the catalytic hydrogenation of lignin during pulping with aqueous alkali and organic solvents. A University of Michigan student continued his study of xylem ring formation in red oak. At Iowa State University, a graduate study of the effects of soil fertilizer on specific gravity and fiber properties of cottonwood was continued.

At the University of Washington, a student continued work on the effect of pulping and bleaching on lignin. A Southern Illinois University student continued his study of reaction rates of polysaccharides in alkaline solution. A new grant was made to Colorado State University for graduate work on layered wood plate systems with interlayer slip.

Exhibits

Laboratory research results were exhibited at three major meetings: the Walnut Workshop at Carbondale, Ill., sponsored by the Forest Service, American Walnut Manufacturers Association, and Southern Illinois University; the Society of American Foresters annual meeting in Seattle; and the Building Research Institute conference in Washington, D.C.

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